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An investigation into the underlying mechanisms of enactment in Working
Memory: the role of action features in aiding action memory performance.

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A dissertation submitted to the University of Bristol in accordance with the
requirements for award of the degree of Doctor of Philosophy in the Faculty of

Life Sciences

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Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: DATE:.....

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Abstract

Enactment (physically performing instructions) has been shown to lead to better working memory and long-term memory performance in children and adults. This effect has been found when enactment is employed during presentation, during test or during both. However, the exact mechanisms underlying this effect are not fully understood. In order to investigate the underlying mechanisms of enactment, this project presented action-object phrases with enactment or verbal presentation but examined separately memory for action and objects at enactment or verbal recall in children and adults (Experiments 1 and 2). This manipulation was employed in order to examine if the enactment benefits rely on motor processing. It was assumed that if the enactment advantage is purely motoric in nature then an enactment benefit would be observed for performed actions but not objects.

Experiments 3 (children) and 4 (adults) employed enactment at presentation for action vs. object memory in order reconstruction and item recognition in order to examine whether enactment facilitates item and order memory for actions. Finally, Experiments 5 (children) and 6 (adults) examined memory for actions and objects in enactment recall, in order reconstruction and item recognition. The purpose of these experiments was to examine whether enactment recall facilitates item and order memory for actions and objects.

The findings overall suggest that physically performing instructions enhances memory predominantly for actions. Contrary to previous research, it was shown that enactment benefits order information, but this effect is specific to actions in enactment encoding. The absence of main enactment effects in Experiments 3, 4, 5 and 6 suggests that the enactment advantage is the product of rich processing of action events and that action-object bindings play a crucial role in the enactment advantage. Finally, the data obtained in these 6 studies provide evidence that enactment encoding and enactment recall may involve different processes.

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1 Chapter 1: Introduction

1.1 Overview and Background of Enactment

1.1.1 Definition

Within cognitive psychology and the study of memory, *enactment* describes the process of physically performing a set of instructions (Engelkamp & Zimmer, 1995). Typically, enactment research involves participants memorising short action-object phrases such as *tap the table* by means of physical performance. Enactment, has been repeatedly shown to lead to better memory performance compared to verbal repetition (Zimmer et al., 2001) both in immediate (Allen & Waterman, 2015) and delayed recall (for a review see Engelkamp & Cohen, 1991). Enactment is also believed to lead to superior memory compared to other conditions such as visual imagery, where participants are asked to imagine performing the actions, (Engelkamp & Krumnacker, 1980) and observation, where participants observe someone else performing the actions (Engelkamp & Jahn, 2003). Enactment has been found to facilitate performance when it is recruited during the presentation phase of instructions (enactment encoding) but also when it is employed during recall (enactment recall) (Engelkamp & Krumnacker, 1980; Cohen, 1981; Koriat, Ben-Zur, & Nussbaum, 1990; for a review see Engelkamp & Cohen, 1991). Typically, in enactment encoding, physical performance takes place during the presentation phase of the material to-be-remembered, while subsequent recall is in verbal or written form. On the contrary, in enactment recall, encoding is usually in auditory or verbal form while physical performance takes place during the recall phase. A final combination is enactment at both the encoding and the recall phase as compared to a verbal baseline condition (e.g. Allen & Waterman, 2015; Saltz & Donnenwerth, 1981). In this double enactment paradigm, there are a total of four conditions, manipulating enactment or verbal encoding and enactment or verbal recall. Studies that have adopted this design, generally report that performance is superior in

enactment conditions, although double enactment (at both encoding and recall) does not lead to double benefits (Kormi-Nouri, Nyberg, & Nilsson, 1994).

Over and beyond the enactment superiority effect at encoding and recall, enactment benefits have been found across different types of recall, populations and study material. For instance, enactment encoding benefits have been demonstrated using a variety of recall techniques such as free recall, serial recall, cued recall and recognition (for a review see Zimmer et al., 2001). Furthermore, superior memory after enactment has been shown with different populations including children (Waterman et al., 2017), young adults (Allen & Waterman, 2015), individuals with autism spectrum disorder (Wodcik, Allen & Souchay, 2011), the elderly (Brooks & Gardiner, 1994), participants with mild cognitive impairment (Pereira et al., 2015) and patients with Alzheimer's disease (Charlesworth, Allen, Morson, Burn, & Souchay, 2014). Finally, while most studies use action-object phrases as the instructions to be memorised, the enactment superiority effect has been demonstrated with different material; for example, enactment effects have been found in studies with or without real objects, with common and bizarre action phrases and with action pairs and object pairs (Engelkamp & Zimmer & Mohr, 1990; Engelkamp, Zimmer, Mohr & Sellen, 1994; Kormi-Nouri et al., 1994). These universal benefits of enactment, as demonstrated across development and experimental conditions, have led researchers to establish the term "*Enactment Effect*" (Engelkamp & Zimmer, 1995).

1.1.2 Enactment History

1.1.2.1 Enactment Encoding

The term *Enactment Effect* was first introduced by Engelkamp and Krumnacker (1980). In this first enactment study, Engelkamp and Krumnacker (1980) asked participants to memorise everyday mini tasks such as "*close the book, comb your hair, tap the table*" in three different conditions; performing the actions, listening to the phrases or imagining the actions. Memory in all conditions was examined using a delayed free recall test. Their findings showed that physical performance led to superior memory recall when compared to

auditory encoding as well as mental imagery encoding. The authors in this paper used the term *Enactment* to describe the physical performance of instructions and the term *Enactment Effect* to describe memory superiority under this condition.

Around the same time period, and independently, Cohen (1981) was also examining memory for physical actions using a very similar paradigm; he tested memory for action-object phrases such as *clap your hands* after enactment encoding and auditory encoding. Using a free recall test, he also found a benefit of enactment encoding over the standard auditory learning condition in both immediate and delayed recall. However, in his paper he used the terminology Subject Performed Task (SPT) to describe enactment encoding, and Verbal Task (VT) to describe verbal encoding. Hence, subsequent research has used the terms *Enactment* and *SPT* interchangeably to refer to physical performance of instructions with an important distinction; SPT is a term mainly used to describe physical performance during the encoding phase of instructions in delayed memory recall. Enactment, however, is a more general term that is used to describe physical performance at the encoding or the recall phase of instructions in immediate and delayed recall (Allen & Waterman, 2015). Further research has since replicated the enactment benefits over verbal and imagery encoding conditions, establishing enactment as a well-documented effect in memory literature (for reviews see Cohen, 1989; Engelkamp, 1997).

1.1.2.2 Enactment recall

Koriat et al. (1990) were among the first to examine physical performance at the recall phase of verbally presented instructions. In their study, encoding was always in verbal form while recall was either verbal or through enactment. At the beginning of each trial, participants were given a study list of 3 or 4 action-object phrases as well as a card indicating the subsequent recall mode (enactment or verbal). They found that enactment recall led to greater memory performance compared to verbal recall as tested in both free and serial recall. Crucially, the same enactment recall effect persisted even when the reported recall mode during presentation did not match the actual recall mode during the test

phase (surprise trials). In this manipulation, participants were told to expect one mode of recall (e.g. enactment recall) but were actually tested in the other (e.g. verbal recall). Their findings showed that participants who expected to enact at recall performed better in the surprise verbal recall compared to those that expected a verbal but received an enactment recall test. These results suggest that it is the anticipation of future enactment recall during encoding that enhances performance, rather than the actual recall mode itself. In other words, they suggested that when participants anticipate recalling the information through enactment, they encode that information in a different manner than when preparing for verbal recall. More specifically, the authors proposed that verbal encoding for future enactment recall activates motoric or visual imagery representations that in turn enhance memory for these events (Koriat et al., 1990). However, the exact nature of these representations is not fully understood.

1.1.2.3 Enactment in both encoding and recall

In the first developmental study on enactment, (Saltz & Dixon, 1982) tested the effects of enactment encoding and enactment recall in children and adults. In this experiment, participants listened to action phrases such as *the horse jumped over the fence*, *the mother cut the paper into small pieces*, and they were asked to either perform these actions or to verbally repeat each sentence twice. During the recall phase, participants were asked to either verbally recall these phrases or to perform them. They found that although both children and adults benefited from enactment at encoding, enactment at recall did not seem to facilitate performance in either age group. However, it is important to note that in this study, the verb of each sentence was used as a cue for recall, and participants' memory was tested for the subject and the object of each sentence (scoring additional points for each). Thus, memory for the motor actions of each phrase was not directly measured. Additionally, there was a delay between encoding and recall, during which participants engaged in a distraction task. Therefore, the study tested long term rather than short term memory (see section 1.2.1). These differences in methodology could perhaps be responsible for the

discrepancy in the enactment recall findings later demonstrated by Koriat et al. (1990) who observed an enactment recall advantage in a series of experiments.

1.1.3 Section Summary

Historically, enactment has been first studied in delayed recall and has shown superior memory performance to verbal memory when employed during the presentation phase (enactment encoding) and during the test phase (enactment recall). Enactment in immediate recall has also shown similar effects. In order to discuss enactment within the context of memory, it is essential to first define the most fundamental memory models.

1.2 Brief overview of key memory models

1.2.1 The Atkinson-Shiffrin Model

According to this model, memory comprises of two main systems that are independent yet related to each other; Short-Term Memory (STM) and Long-Term Memory (LTM). STM refers to a passive storage system of limited capacity that holds information for a very limited amount of time estimated to be 30- 40 seconds. Long-term memory is thought to be an unlimited capacity storage system where information is potentially accessible throughout the life span, although memories may change or decay overtime (Atkinson & Shiffrin, 1968). The model assumes that information entering STM via sensory input, will be shortly lost unless it is passed on to Long-Term Memory (LTM) for potentially permanent storage. Typically, in STM tasks aiming to test verbal memory, participants are exposed to verbal stimuli such as numbers or words which they then repeat back in the correct order. It is generally thought that the number of items that can be held in STM ranges between 5 to 9 with most people scoring an average of 7 (Miller, 1956). This model has been criticised for portraying a very passive view of memory storage and indeed more recent models propose more dynamic memory systems (e.g. Baddeley, 1986). Nevertheless, the terms STM and LTM are still used very frequently in the literature, often to denote time frames rather than properties.

1.2.2 The Working Memory model

Working memory refers to a limited capacity cognitive system that underlies complex thinking (Baddeley, 2007). The model of Working Memory (WM), as developed by Baddeley and Hitch (Baddeley & Hitch, 1974; Baddeley 1986) aims to account for the temporary mechanisms involved in the processing and manipulation of information in the human mind. Contrary to the concept of STM which describes a passive storage system, WM as the name suggests, proposes a dynamic and active system that not only maintains, but also manipulates information, often in the face of distraction (Baddeley, 1986). According to this model (Baddeley, 2000), WM consists of four subsystems capable of parallel processing; the central executive, the phonological loop, the visuospatial sketchpad and the episodic buffer. The central executive is an attentional control system that directs and allocates attentional resources as needed. This system is also responsible for the control of action as well as other cognitive functions such as problem solving (Baddeley, 1996). The phonological loop is a limited capacity storage system concerned with phonological information, for instance acoustic and verbal stimuli. In other words, this system processes and temporarily maintains speech-based information. The maintenance of information by this system is dependent on rehearsal whereby information that is not refreshed by some form of phonological repetition will be lost. The visuospatial sketchpad is a system which process and maintains visual and spatial information. As with the phonological loop, this is a temporary storage system and information that is not rehearsed will be lost. Finally, the episodic buffer, is thought to integrate and coordinate information from the other sub-systems and from long-term memory. It is thought to have a capacity of four multidimensional chunks or episodes, each including for example visual and verbal information (Baddeley, 2010).

1.2.2.1 Working Memory measures

WM capacity is often measured using complex span tasks that aim to tap both the storage and the processing of information. In such tasks, participants may be exposed to a series of stimuli for later recall, while at the same time they are required to engage in some parallel processing. In a typical example of the complex span task, participants read out a series of sentences and are required to memorise the last word of each of those sentences for later serial recall (Daneman & Carpenter, 1980). Complex span tasks are used to measure verbal or visuospatial WM capacity (Conway et al., 2005). For example, in a complex WM span that aims to capture visuospatial memory, participants may have to remember the location of various targets while engaging in a concurrent visual search. It has been suggested that in such tasks, performance depends on domain-specific storage and domain-general processing (Bayliss, Jarrold, Gunn, & Baddeley, 2003). Complex span task performance has been linked to fluid intelligence, educational achievement, reading and mathematical abilities as well as general higher cognitive functioning (Conway, Kane, & Engle, 2003). However, although these tasks may provide information regarding WM capacity, they do not examine directly the interplay of the factors contributing to performance. That is, to what extent memory capacity and information processing independently predict WM performance (Bayliss et al., 2003).

1.2.2.2 Development of WM and Underlying Mechanisms

Bayliss et al. (2003) reported developmental evidence suggesting that WM performance involves both domain-specific storage and domain-general processing and that both factors independently contribute towards WM performance. Furthermore, they demonstrated that there is a third factor involved in WM performance, the executive coordination of the domain-specific storage and domain-general processing. Crucially, these factors remained stable across development, suggesting that both children and adults face the same WM constraints (Bayliss et al., 2003).

Further evidence regarding the role of WM subsystems and their development was provided by Gathercole, Pickering, Ambridge, and Wearing (2004) who examined the development of WM in children ranging from 4 to 15 years of age. Their research suggests that although the storage capacity of each subsystem may increase with age, the structure and relationship between the subsystems (the central executive, the phonological loop and the visuospatial sketchpad) remain relatively stable throughout development (from the age of 6 onward). According to Gathercole et al. (2004) each WM subsystem is distinct, yet highly correlated with each other. More specifically, although measures of the phonological loop and the visuospatial sketchpad were found to be moderately correlated with each other, both were highly correlated with central executive tasks. These data fit the WM model proposed by Baddeley and Hitch (1986) (see also Kane et al., 2004) and provide evidence for the structure of the system across development.

In conclusion, the mechanisms involved in WM are a combination of domain-specific retention and domain-general processing as well as the ability to co-ordinate the two in a manner that maximises efficiency and minimises losses (Jarrold & Towse, 2006). Furthermore, it appears that although storage capacity and processing efficiency may increase with age, these principle mechanisms as well as their inter-relationships remain relatively stable across development (Gathercole et al., 2004).

1.2.3 Action Memory -Norman & Shallice Model and the Central Executive

Norman and Shallice (1980) first proposed an attentional control of action that was later adopted by Baddeley as a possible candidate for the role of central executive in the WM model (Baddeley, 1986). According to Norman and Shallice, the Supervisory Attentional System (SAS) is a system primarily concerned with the control of attention and action. They proposed that action sequences, once learned, are relatively automatic and require minimum attentional control. These sets of automatic action sequences were named “schemata” and thought to be activated when the appropriate internal or external triggers are present. The

automaticity refers to the ability to execute these action sequences without any conscious effort or awareness (Norman & Shallice, 1980). Automaticity in this context resembles the term of expertise. For instance, consider the complex motor behaviour of walking. Initially, learning a task like this may require attention and conscious effort but once the motor behaviour is learned, there is no need for conscious monitoring anymore. There are, however, instances during which the adopted schemata may run into difficulties and thus attention is required to resolve the issue.

In more detail, the SAS is employed in a series of situations and processes such as in decision making, planning, the consolidation of novel and newly learned material, or when automatic schemata reach a halt, in dangerous or difficult situations and in the inhibition of habitual responses (Norman & Shallice, 1980). For example, consider making a cup of tea; the series of actions to be performed should be relatively automatic (assuming the agent has performed this process many times in the past), allowing attentional resources to be allocated elsewhere. However, an unexpected event may interfere and may urgently require the agent's full attention, such as accidentally spilling boiling water on one's hand. Such events will trigger the involvement of the SAS and will engage attentional resources. Baddeley (1986; 2007) suggested that working memory's central executive is a system concerned with similar operations including the control of action. Perhaps the lack of a cognitive model that incorporates a motor system as a fundamental part of cognition, stems from this early model that gives action a purely automatic and a low-level processing role.

1.2.4 Summary and conclusions

The most influential models of memory within cognitive psychology are concerned with the encoding, retention, processing and manipulation of phonological, visual and spatial information as well as with attentional systems. The role of action is not directly addressed, and the models discussed above do not fully accommodate the control and processing of action within the cognitive memory system. However, the study of enactment reveals that

physical action aids memory performance in cognitive tasks, raising the need to revisit the role of motor action in higher cognitive functioning. The next section discusses evidence regarding the active involvement of action in working memory and explores the underlying mechanisms of enactment based on findings from the literature.

1.3 Enactment and Working Memory

1.3.1 Enactment research in WM

As mentioned above, the enactment literature has traditionally focused on delayed recall, aiming to study the long-term effects of enactment. However, in the recent years there has been a growing body of literature investigating enactment within the WM context. Gathercole et al. (2008) was the first to examine enactment in WM in children. In this study, participants encoded instructions verbally while recall was either verbal or through enactment. The instructions included two actions (touch and pick up), a series of objects (e.g. eraser, pencil, ruler) each in two different colours (e.g. yellow ruler, blue ruler), and a set of containers (e.g. box, bag, folder) also in two different colours each (e.g. black box, green box). Those stimuli created a series of instructions such as “touch the red pencil, then put the yellow ruler in the black folder, then touch the blue eraser”. There was not a fixed number of stimuli per trial but rather, the task followed a span procedure. That is, the task started with 1 item per trial and items per trial increased until the participant failed to recall two trials in a given span correctly. The findings from this study showed that enactment recall led to superior memory performance compared to verbal recall for each element of the instruction sequence. Additionally, this study also employed a series of WM measures, namely forwards digit recall span (FDR) and Backwards digit recall span (BDR). In the FDR, participants listen to a series of digits which they have to immediately recall in the correct order much like a classic STM span task. This task typically follows a span procedure as described above for the main task. In the BDR task, participants listen to a sequence of numbers and they are asked to recall them in the reverse order, starting with the last one

and moving serially backwards to the first presented item. The latter task is thought to be a measure of central executive, or at least it is used as such, and again follows a span procedure. Notably, performance for verbal recall in this study did not correlate with either the FDR or the BDR task. However, strong correlations were observed between enactment performance and those two WM measures, suggesting the involvement of WM in enactment recall performance in children.

Allen and Waterman (2015), first investigated the benefits of enactment in WM at both the encoding and recall phase in adults. Participants encoded short action-object phrases either verbally or through enactment while recall was also either verbal or enacted. The material used in this study, were eight abstract two-dimensional shapes (e.g. hexagon, circle, triangle) and 6 actions (e.g. flip, push, spin). Each trial consisted of five action-object pairs. The use of arbitrary novel action-object pairs in this study, ensured that the task would tap on WM processes, avoiding semantic and long-term associations. Participants completed each of the four conditions in a separate block. The findings showed that enactment at encoding led to better memory performance, but this effect was significant only for verbal recall but not enactment recall. Enactment at recall led to higher performance rates compared to verbal recall independently of encoding mode. The authors suggested that physical performance at the encoding phase is particularly beneficial for future verbal recall as it provides an additional form of encoding that supports verbal memory. Similarly to Koriat et al. (1990), Allen and Waterman (2015), suggested that enactment at recall, reinforces the recruitment of motoric representations during the presentation phase which in turn benefits memory performance.

Enactment at both encoding and recall in children in WM has also been investigated recently. Jaroslawska, Gathercole, Allen and Holmes (2016) examined memory for action-object phrases in school children using a similar design to Allen and Waterman (2015). Their instructions were identical to Gathercole et al. (2008) described above. This study found enactment benefits at both the encoding phase (for both enactment and verbal recall) and at the recall phase (after both enactment and verbal encoding) (For a full description of the

study see Chapter 2, section 2.1.1). These findings replicate the results of Gathercole et al. (2008), who found strong enactment recall benefits compared to verbal recall and further show that children also benefit from enactment encoding. Nevertheless, neither Allen and Waterman (2015), nor Jaroslawska et al. (2016) used additional WM measures to examine further the relationship between enactment performance and WM resources.

Yang, Gathercole and Allen, (2014; see also Yang, Allen & Gathercole., 2016) specifically aimed to study whether WM contributes to enactment performance and if so, in which manner. This study used very similar stimuli to the instructions used in Gathercole et al. (2008) with the difference that the number of actions increased from two to six verbs. In this study participants encoded instructions verbally for later implementation (enactment or verbal recall) while engaging in articulatory suppression and backwards counting (Experiment 1) and additionally spatial tapping (Experiment 2). For the articulatory suppression, participants saw a random 3-digit number on the screen and were asked to repeat it continuously for the duration of the presentation. In the backwards counting condition, participants saw a number on the screen but in this condition, they had to count in decrements of two for the duration of the trial. Finally, for the spatial tapping task participants had to tap a series of locations in a fixed order for the duration of the trial. Articulatory suppression was chosen as a phonological loop distractor, backwards counting was aimed at disrupting executive functions and spatial tapping aimed to disrupt visuospatial WM. Their results showed that although the distractor tasks impaired overall performance in both enactment and verbal recall, the enactment benefit over verbal recall remained stable across conditions. Overall, the authors suggested that executive functioning plays an important role in the ability to follow instructions, but that enactment does not rely on any of the sub-components of WM. This is because the enactment advantage over verbal recall remained evident regardless of the nature of disruption. These findings suggest that enactment (or essentially action memory) may rely, at least partly, on mechanisms not captured by WM tasks.

In summary, studies that have tested enactment in WM have repeatedly shown benefits in WM performance after enactment encoding as well as enactment recall in both children and adults. Additionally, the findings from these studies show some evidence for the involvement of WM resources in enactment in both children and adults. However, at least in adults, there seems to be an enactment advantage residual that remains unexplained when WM components are blocked by distractors (Yang, Gathercole & Allen, 2014; Yang, Allen & Gathercole, 2016). This raises questions regarding the nature of the underlying mechanisms of the enactment advantage. In other words, if WM is not mediating enactment performance then which system is responsible for the enactment effect? The rest of the introduction will explore these issues.

1.3.2 Enactment within the existing WM model

The Working Memory Model, as described by Baddeley and Hitch (1986) does not contain a subsystem dedicated to the processing, coordination or monitoring of action. Yet, it can be argued that action or motor memory is a central component of human functioning and the lack of a theoretical model that attempts to explain the coordination of action and cognition is a major gap in cognitive psychology. According to the WM model, possible candidates for the processing and monitoring of action are the Episodic buffer, the Visuospatial sketchpad and the Central Executive. According to Baddeley (2000), the episodic buffer- a domain general subsystem, is concerned with the binding of information from the other WM subsystems and LTM. The multidimensional representations in this system are thought to be accessed by conscious awareness. While the episodic buffer could perhaps be a key component in understanding the enactment effect, its exact mechanisms are not yet fully specified. Therefore, although the Episodic Buffer cannot currently serve as a candidate system that could be fully accountable for the enactment advantage, it is thought to play a key role in the binding of multimodal information. In turn, this binding process may be a determining factor in enactment, as enactment tasks involve binding of motor, verbal and visuospatial information. Thus, the episodic buffer provides a useful framework that may

in part explain some of the processes involved in the enactment advantage. The other WM candidates are discussed below.

Within the Working Memory by Baddeley and Hitch (1986), the Visuospatial Sketchpad is responsible for processing visual and spatial information but not motor or action information per se, although it has been suggested to be involved in motor processes as well. However, evidence suggesting that spatial and motoric information are processed separately comes from Smyth and Pendleton (1989; 1990) who argued that spatial and motor memory are two distinct types of memory. According to their account, movements directed towards spatial locations in the environment involve different mechanisms than bodily patterns or configuration movements. An example of the former category would be pointing to a specific location while an example of the later would be clenching one's fists. In their study (1989), participants were shown a series of hand movements that they had to memorise for later performance. During this phase they also engaged in two different distractor tasks, a spatial task (finger tapping in a certain order) or a motor task (repeatedly squeezing an object). Performance in the main memory task was impaired after the motor distractor but not after the spatial distractor encoding.

In the second experiment reported in this paper, Smyth and Pendleton (1989) examined the effects of a concurrent motor distractor and a visuospatial distractor (Corsi Task) on motor and spatial memory performance. Corsi is a visuospatial WM task in which participants are asked to memorise a series of locations on a set of blocks (or on a grid) for later serial recall. The authors found that visuospatial memory was impaired after the spatial but not the motor distractor task. The authors took this as evidence to suggest that the Visuospatial Sketchpad, as described in the WM model, cannot account for motor memory processes, other than playing a part in the initial processing of seen movements (Smyth & Pendleton, 1989). In a subsequent experiment, Smyth and Pendleton (1990) also observed that remembering spatial locations while trying to retain a set of motor movements for later recall, did not affect memory for those motor movements but it did significantly disrupt order information of the remembered items. This latter finding may indicate that although motor

performance does not depend on VSP WM, perhaps the manipulation of information (i.e. retaining order information) may relate to WM. The authors highlighted the need to update the classic Working Memory model to include a subsystem dedicated to motor processes (Smyth & Pendleton, 1989).

Furthermore, the study by Yang, Gathercole and Allen (2014) (see also Yang et al., 2016) found that spatial tapping, aiming to disrupt VSP processing, as well as BDR, aiming to disrupt the central executive, did not eliminate the enactment advantage over verbal recall. These findings suggest that the enactment advantage does not rely on neither the central executive nor the visuospatial sketchpad.

The central executive is thought to be involved in motor processing as explained in the WM section above. However, according to this view, motor and action processes are thought to operate in an automatic manner that does not actively require attention and information manipulation. Yet as discussed above, enactment benefits extend beyond central executive disruption.

1.3.3 Section Summary

The evidence presented in this section suggest that enactment leads to superior memory performance in WM in adults and in children. Physical performance of instructions leads to better WM performance at both the encoding and the recall phase. Developmental studies have shown that enactment performance is strongly related to WM and more specifically the central executive. Studies with adults have not compared enactment performance and WM but they have studied the relationship between the two using distractor tasks during enactment. Those studies have shown that the enactment advantage remains intact after WM disruption, suggesting that the mechanisms that support enactment are not captured by WM measures. Furthermore, the WM model by Baddeley (1986) cannot directly accommodate this enactment advantage within the existing WM subcomponents. The results presented in this section, further raise the question of what the underlying

mechanisms of the enactment effect are. The next section explores evidence from the literature suggesting that enactment relies on motor information and processing.

1.4 Underlying mechanisms of enactment

1.4.1 Motor Representations

In terms of the underlying mechanisms of the enactment effect, it could be suggested that enactment leads to deeper processing of information thus enhancing memory for the studied material. According to the *levels of processing* account (Craik & Lockhart 1972), deeper processing, such as making semantic connections or engaging in elaborative rehearsal, leads to superior memory for the encoded material. In other words, the degree of mental elaboration on encoded information will affect subsequent memory for that information (Craik & Tulving, 1975). However, this theory focuses mainly on semantic associations; for example, linking new information to pre-existing knowledge and making elaborate connections between mental representations and concepts. Levels of processing has been predominantly studied in the verbal and visual domains. Thus, deeper processing can be utilised to potentially facilitate performance in both verbal and enactment conditions, hence, it cannot explain the enactment superiority effect. Nevertheless, future research could examine the integration of higher cognitive processes (e.g. semantic associations) within motor movements and how they may facilitate deep processing.

Further, it has been suggested that enactment superiority may rely on dual-coding (Paivio, 1986). According to this view, the encoding of enacted instructions should draw upon both verbal storage as well as motor information associated with the performed actions. In turn, this dual form of encoding and retention (verbal-motor) leads to better memory performance compared to verbal-only presentation. However, this does not directly explain the enactment at recall superiority when participants are asked to recall the verbally presented instructions by enacting them. This is because, in this type of design, presentation is verbal and thus encoding relies on one modality. Yet enactment at recall leads to superior

memory performance compared to verbal recall (e.g. see Allen & Waterman., 2015; Gathercole et al., 2008; Koriat et al., 1990). This effect has led researchers to argue that enactment recall benefits reflect motor representations formed during verbal encoding in anticipation of later action recall (Koriat et al., 1990). However, the exact role or nature of these motor representations in aiding memory performance in such cognitive tasks is not fully explained under one unified framework. For example, it is not clear whether motor representations during enactment encoding draw on the same mechanism as the motor representations during verbal encoding for later enactment recall.

It has been suggested that if enactment at encoding and enactment at recall involved separate mechanisms, then one would expect that enactment at both stages should exhibit double benefits (Jaroslawska et al., 2016; Kormi-Nouri, Nyberg & Nillson., 1994). In other words, performance at both encoding and recall should be superior to enactment only at encoding or only at recall because the different benefits should be additive. However, most of the research in this area suggests that enactment at both encoding and recall does not exhibit any dual benefits (Jaroslawska et al., 2016). In turn, this suggests that enactment at encoding and recall may rely on the same mechanism that processes motor representations (Jaroslawska, Gathercole, & Holmes, 2018). However, it is not clear what type of information is defined as motor representations (i.e. the motor movement or the action event as a whole). Nevertheless, enactment, in this context, can be seen as a form of action memory that facilitates overall memory performance by feeding motor information into higher cognitive memory systems. For example, Engelkamp and Zimmer (1984) argued that enactment relies on motor information, after observing shortened reaction times for the recognition of similarly enacted movements compared to verbally studied material. In a subsequent study they also found that motoric (but also conceptual) similarity of distractors impaired recognition after enactment performance at encoding (Engelkamp & Zimmer, 1995). Additionally, Koriat and Pearlman-Avni (2003) found that enactment led to memory organisation (similar items grouped together at recall), but this effect was specific to motor movements rather than conceptual information as in verbal learning. Finally, the studies by

Smyth and Pendleton (1989; 1990) discussed above also show evidence for a motor system that facilitates memory performance for motor sequences. Together, these findings suggest that enactment relies on motor processing, at least to some extent. Further evidence to support this assumption come from neuro-imaging studies of enactment.

1.4.2 Neuropsychological evidence

In addition to behavioural evidence suggesting that the enactment effect relies on motor information, a number of brain-imaging studies also suggest the involvement of motor brain areas in enactment. For example, Nilsson et al. (2000) examined brain activation after enactment, observation or verbal learning using PET (Positron Emission Tomography). Their findings suggested that motor cortex activation was strongest after enactment encoding, less after observation and least after verbal learning. This finding was further replicated by James and Swain (2011) who studied enactment versus observation using fMRI. In this latter study, children learned novel action-object phrases, half of them by self-performance and half by observation. More specifically, this study developed a series of nonwords as the actions (e.g. quaning, panking, ratching) to be performed on novel objects. Each object was associated with one action. Participants learned half of these action-object pairs by performing the actions on each object themselves and half of them by observing the experimenter performing the actions on the objects. During the fMRI session, participants were auditorily presented with the actions and visually exposed to the objects. Actions and objects were divided in three categories; performed, observed and novel. Actions and objects were presented separately. The authors found that auditory presentation of the performed actions, increased brain activity in motor, parietal and frontal areas to a greater extend that observed or new actions did. Furthermore, activity in motor areas was only evident after the self-performed condition. Additionally, compared to the visual presentation of objects learned via observation, visual presentation of the objects that had been learned through self-performance resulted in greater activity in motor areas. These results are consistent with

previous studies suggesting that the physical enactment superiority has motor underpinnings.

Similar findings were also shown by Nyberg et al. (2001), who examined brain activity and enactment using PET. In this study, participants encoded action-object phrases in three different conditions; enactment in which they performed the actions symbolically without any objects present, motor imagery where they were asked to imagine performing the actions, or verbal encoding during which they silently rehearsed the material. Participants completed the encoding phase inside the scanner so that brain activity was recorded during the encoding phase. At recall, participants were given the action and were asked to generate the object paired with it during encoding. The behavioural results showed significantly greater memory performance in the enactment encoding condition compared to both motor imagery and verbal learning. The PET results however, suggested that both enactment and motor imagery activated motor brain networks during recall, even though behavioural data showed superior memory performance after enacted but not motor imagery encoding. Additionally, the authors reported that activation during encoding and activation during recall, although both involving motor areas they still exhibited different patterns of activity. The authors suggested that different neural systems are involved in the processes of encoding and retrieval.

In sum, a number of studies have observed the involvement of the motor cortex after enactment encoding or recall, suggesting that motor activation is greater after self-performed actions compared to observation or verbal learning in both children and adults. Additionally, the study by Nyberg et al. (2001), also found that motor imagery led to similar brain activation to actual motor performance. These findings are consistent with the simulation theory (Jeannerod, 2001), which suggests that the motor systems in the brain operate in a similar manner for both executed and imagined actions. Jeannerod (2001), draws on evidence from the neuroscientific literature for instance that there is a significant overlap of motor cortex activation during physical and imagined action to suggest that the brain internally simulates states of actual physical performance.

Overall, the evidence reviewed in this section provide support for the assumption that the enactment advantage, relies at least partly, on motor systems. Additionally, the study from Nyberg et al. (2001), also suggested that brain activation patterns during encoding and recall differ although the systems involved in both phases may overlap. This finding may provide partial support for the claim that enactment encoding, and enactment recall rely on different processes. However, it is important to note that in this study participants encoded information via enactment or motor imagery, but they did not perform any actions during recall. Therefore, perhaps a different activation pattern may be expected given the different modes of encoding and recall.

1.4.3 Motor store

The literature examining the underlying effects of enactment, seems to be quite consistent in observing the involvement of motor processes in facilitating memory under enactment (e.g. Engelkamp & Zimmer, 1989; Jaroslawska et al., 2016) and the neuroscientific evidence provided above support this hypothesis. Therefore, it is generally thought that enactment relies on motor processes however it also seems that Working Memory plays a role in enactment, mainly in terms of the monitoring, manipulation and co-ordination of movements. This assumption is based on studies that have observed strong relationships between enactment performance and WM measures (e.g. Gathercole et al., 2008; Waterman et al., 2017). Additionally, the studies that have examined WM disruption and enactment performance in adults (Yang et al., 2014, Yang et al., 2016, see section 1.3.1), although they observed a clear enactment advantage over verbal repetition, they also found that WM distractors significantly impaired enactment performance. This suggests at least some involvement of WM in enactment performance in immediate recall.

Hence, the literature suggests that enactment relies to some extent on motor processing which benefits performance during enactment encoding and during enactment

recall. However, the exact mechanisms involved, as well as the processing of motor information within WM, are not completely understood.

A candidate theoretical framework that could potentially address these issues is the one-component hypothesis or motor store hypothesis (Jaroslawska et al., 2016; Jaroslawska et al., 2018). This view argues that action memory relies on a *motor store* system (Jaroslawska et al., 2016). According to the one component hypothesis, the motor store is a system that temporarily holds and manipulates temporal, spatial and motoric action information (Jaroslawska et al., 2018). Consistent with this model, enactment encoding and enactment recall rely on the same mechanisms of motor representations (regulated by the motor store). Evidence in the literature supports this assumption as enactment studies in WM (e.g. Allen & Waterman, 2015; Jaroslawska et al., 2016; Waterman et al., 2017), although they have observed enactment benefits at both encoding and at recall, they have not found additive effects. In other words, double enactment (at encoding and at recall) does not lead to superior performance than enactment at one stage does (either enactment encoding or recall).

Furthermore, the motor store hypothesis was investigated directly by Jaroslawska et al. (2018). In this study the researchers followed a similar paradigm to Yang et al. (2014), whereby participants encoded instructions in written form (presented on a screen) while they simultaneously engaged in a series of distractor tasks. The distractors tasks aimed to disrupt the phonological loop (articulatory suppression task), the central executive (backwards counting) and the motor store (motor disruption task). The latter task involved participants making three consecutive hand movements (Experiment 1) and a series of three consecutive arm movements (Experiment 2). The instructions were identical to Gathercole et al. (2008) (see section 1.3.1.). At the recall phase, participants were asked to either enact or verbally recall the material. As in Yang et al. (2014; see also Yang et al., 2016), articulatory suppression and backwards counting disrupted performance in both enactment and verbal recall but the enactment advantage remained intact. The enactment advantage was also observed after the motor distractor in Experiment 1 when it involved hand movements but

not in experiment 2 which involved arm movements. According to the authors, the motor task in Experiment 1 failed to disrupt enactment performance because participants may have used verbal rehearsal to guide their hand action (e.g. repeat sub vocally the actions performed by their hand). The motor distractor used in Experiment 2, significantly disrupted enactment recall performance. Overall, the authors suggested that enactment benefits relied on motor processes which are operated by the motor store system. Further, they proposed that the motor store should be incorporated within the existing WM model as an additional WM subcomponent.

1.4.4 Section summary

In conclusion, evidence from both behavioural and neurophysiological studies, support the idea that enactment superiority relies on motor processes. Furthermore, research on WM and enactment suggests that these motor processes operate under a potential WM subsystem, the motor store. According to this view, the motor store is responsible for the maintenance and manipulation of motoric and temporal information. Additionally, this view assumes that both enactment encoding and enactment recall involve the same processes, operated by the motor store. However, it is unclear whether the motor store processes action events as a whole (e.g., actions, objects, object features, and other spatial information) or whether it is specifically dedicated to motor actions per se.

1.5 Deconstructing Enactment

In order to gain a better understanding of the cognitive mechanisms underlying enactment, the next section reviews some evidence regarding the nature of information benefiting from physical performance.

1.5.1 Enactment and the item-order hypothesis

1.5.1.1 Item and order

It has been proposed that memory for individual items and memory for their order are two distinct types of information that involve separate mechanisms (Healy 1974). Item information refers to the individual characteristics of a stimulus while order information refers to the order in which a series of stimuli are presented (Bjork & Healy, 1974). Relational information refers more generally to the relationship between items, for instance semantic or categorical associations in a study list but also order information (Hunt & Einstein, 1981). Further evidence for the dissociation between item and order information comes from patients with selective STM impairments. Attout, Van Der Kaa, George and Majerus (2012), observed that patients with different STM impairments showed selective impairment for either item or order information. More specifically, they suggested that both item and order information involve attentional mechanisms and long-term associations, but that order information may additionally involve spatial attention. However, it has also been suggested that item and order information, as studied in verbal Working Memory, may tap into the same mechanisms (Camos, Lagner & Loaiza, 2017).

1.5.1.2 Item and order Hypothesis

Nairne, Riegler, and Serra (1991), observed that some encoding conditions, such as enactment, may lead to much better item memory than verbal encoding, while disrupting order information. This effect is known as *the item-order hypothesis*. The item-order hypothesis extends beyond enactment to other special encoding conditions, for example, the generation effect which demonstrates that item but not order memory for self-generated material is superior to memory for standard word lists. More specifically, Nairne et al. (1991) examined the item-order hypothesis in the generation effect by asking participants to memorise study lists that included full words (e.g. banana) and incomplete words (ban_ na). They showed that although participants' performance was greater for item information after

generation encoding using a recognition test, order information was impaired compared to a standard study list condition in a reconstruction test. In this study, a reconstruction test was given after a trial (on half of the trials) while the recognition test was only given at the end for the whole set of stimuli (144 items). In general, it is believed that most encoding conditions that amplify item information disrupt order memory (Golly-Haring & Engelkamp, 2003). In turn, this may imply that item and order information may rely on the same mechanisms, or else, that item and order information are separate yet constraint by limited attentional resources. Other encoding conditions that benefit item but not order have been found in the bizarreness effect (McDaniel, Einstein, DeLosh, May & Brady, 1995), word-frequency effect (DeLosh & McDaniel, 1996) and perceptual interference effect (Mulligan, 1999), and enactment is no exception.

1.5.1.3 Item and Order hypothesis and Enactment

Although the item-order literature focuses primarily on immediate memory recall, research on the item-order hypothesis, as applied to enactment, has mainly involved delayed recall and long-term retrieval. Consistent with the item-order hypothesis, encoding conditions that increase stimuli salience do so at the expense of order information (Golly-Haring & Engelkamp, 2003). Olofsson (1996), using an order reconstruction task, showed that verbal encoding led to significantly greater order performance compared to enactment encoding. Further, Engelkamp and Dehn, (2000) examined the item-order hypothesis in enactment versus observation. Under these conditions, participants either performed action-object phrases (SPT) or observed the experimenter performing them (EPT). Engelkamp and Dehn (2000), also found that enactment led to greater memory for item information (as tested using a recognition task) compared to observation encoding, but that order memory was significantly better after observation compared to enactment (using an order reconstruction task). Again, the authors assumed that in enactment encoding, the focus is shifted from context and other relational information such as the presentation order to the

individual properties of each action. This effect of enactment superiority only for item and not order information has since been replicated (e.g. Engelkamp, Jahn, & Seiler, 2003).

Furthermore, Schult, Von Stülpnagel, and Steffens (2014) examined the item-order hypothesis in SPTs and EPTs for unrelated action-object phrases (e.g. loading a dishwasher, painting a picture) versus related action sequences (e.g. barbequing, cooking a pizza, making pancakes). This study found that although compared to unrelated action-object phrases, action sequences do increase order information in enactment, order performance was still superior after observation. Additionally, in the Koriat et al. (1990) study mentioned above, the authors also examined order and item memory performance after enactment recall in a post-hoc analysis. Their findings suggested that order memory showed greater impairment than item memory when the recall mode did not match participants' expectations. This may suggest that order information is embedded in the encoding context. For instance, encoding order information for future verbal recall and encoding order information for future motor recall may involve different processes.

Overall, the studies that examined enactment in long-term memory suggest that enactment facilitates item memory at the expense of order information. Research on WM and enactment however, has examined memory in serial recall, which involves order information, and has consistently found strong enactment effects in both children and adults (e.g. Gathercole et al., 2008; Allen & Waterman, 2015; Yang et al., 2014). Although order reconstruction and serial recall are not the same processes, successful performance in serial recall requires memory for order. This discrepancy in the literature, perhaps suggests that enactment in WM and enactment in LTM may involve different mechanisms or processes. Thus, further examining the relationship between item-order information and enactment in WM may contribute better to the understanding of the enactment phenomenon. For instance, if enactment performance in WM is mediated by the motor store (see section 1.4.3), then it might be expected that order information is facilitated by enactment in immediate recall, as motor processing is thought to involve sequential information (Ashe, Lungu, Basford, & Lu, 2006).

1.5.2 Action and Object Memory in Enactment

Enactment has been mainly studied using short action-object phrases such as “push the pen” and “tap the coin”. However, the individual effects of enactment separately for the actions and for the objects involved in typical enactment instructions, remain relatively unknown. Examining separately memory for actions and objects in enactment may shed light into the underlying processes of the enactment effect. Indeed, direct as well as post-hoc evidence suggests that enactment may affect memory for actions and objects in a different manner. Nevertheless, enactment and memory for actions and objects has been examined directly only in two studies (Engelkamp et al., 1990; Engelkamp, Mohr, & Zimmer, 1991), both in delayed recall. Most of the evidence suggesting a different memory pattern for actions and objects in enactment comes from post-hoc observations in the literature. This section examines this evidence.

A major distinction between actions and objects (described by verbs and nouns respectively), is that they belong to different grammatical and semantic categories. In terms of brain processing, there is evidence of neural segregation of the processing of actions and objects, based on semantic content rather than grammatical knowledge (for a review see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). Vigliocco et al. (2011) suggest that there are no distinct brain signatures related to different grammatical class of words but there are distinct neural correlates in terms of the semantic processing of words. This difference in semantic processing suggests that the action and object words in the brain are processed in terms of their conceptual features rather than their grammatical markers. In turn, this suggests that conceptual features are not amodal but rather, the semantic system is closely linked to perception, action and emotion (Barsalou, Simons, Barbey & Wilson, 2013). For instance, Pulvermüller, Moseley, Egorova, Shebani, and Boulenger (2014) proposed that action perception circuits (APC) in the brain link motor and sensory information so that they create “action representations” which are activated when similar actions are perceived.

Further they suggested that the APCs connect or merge with higher-order circuits to attach meaning to motor actions and objects representations. Thus, according to these accounts, motor processes are closely linked to perception and cognition.

From a semantic standpoint, a major difference between nouns and verbs is their concreteness; for example, nouns refer to very specific, concrete concepts (usually physical objects) while verbs are considerably more abstract which in turn makes them more challenging to memorise (Engelkamp et al., 1991). Verbs are complex concepts that can be concretised by the use of contextual information such as nouns (Engelkamp et al., 1990). For instance, the verb “kick” will carry a different meaning, and will refer to a different motor action, if it is paired with “ball” (i.e. kick the ball) compared to “door” (i.e. kick the door). Taking this even further, the verb “kick” will have a completely different meaning if it’s followed by the word “habit” (i.e. kick the habit). Hence, a verb may often represent an abstract action which becomes specific when it is followed by an object on which to be performed. Objects on the contrary, are stable perceptual units (Engelkamp et al., 1990). Consequently, it is suggested that because actions are more abstract concepts, memory for objects is generally much greater than memory for actions (Engelkamp et al., 1991). Finally, it is believed that because objects (nouns) refer to stable perceptual stimuli, they provide better contextual information and therefore they facilitate relational information to a greater extent than verbs do (Engelkamp et al., 1990). Evidence for this assumption come from a series of studies that examined memory for action pairs and object pairs under enactment or verbal encoding discussed below.

1.5.2.1 Action-Object memory at encoding

As mentioned above, only a few studies have examined the differences between memory for actions and objects in enactment. For example, Engelkamp, et al. (1990) examined memory for verb pairs versus noun pairs under modality-specific or verbal encoding in five experiments. To do this, they created pairs of unrelated actions (e.g. to cut,

to drive) and objects (e.g. banana, house). In these series of experiments, modality specific encoding involved enacting the actions and imagining the objects and was compared to auditory presentation. Memory for item information was assessed using a free recall task, showing that both verbs and nouns benefited from modality specific encoding, although the effects were more prominent for verbs (Experiments 1&2).

Additionally, the authors examined memory for categorically-related lists (taxonomic) and semantically-related (episodic) lists under verbal encoding only (Experiment 3). The taxonomic lists included action and object pairs that belong to the same category (e.g. “to wipe”, “to scrub”), (“hammer” “nail”). The episodic lists contained actions or objects that could be part of an “episode”. For instance, a verb sequence for driving a car (“to start”, “to drive”, “to turn”) was one of the “episode lists” for verbs, and the theme “at school” was one of the “episodes” for objects (e.g. books, pencils, blackboard). Additionally, half of the participants were explicitly told that items were grouped in taxonomic and episodic lists and were instructed to use that information to aid performance. The other half were not given any additional information. Their main findings showed that verbs clustered in episodic lists were better recalled than those in taxonomical lists, but overall nouns were better recalled in all conditions. The authors concluded that verbs do not provide good relational information as they were organised in episodic and taxonomic lists more poorly than nouns.

In the 4th experiment reported in this paper, the authors examined memory for episodic lists under modality specific or verbal encoding for verbs and nouns using a similar paradigm to Experiment 3. However, this time they examined only episodic lists in category encoding (participants were told items were categorised in lists) or no-category encoding in free recall. The results showed that, contrary to nouns which exhibited the same recall rates under verbal and modality specific encoding, verb recall rates greatly benefited from enactment encoding of the episodic lists. However, this was the case only when no-categorical instructions were provided. For the categorical group, participants were asked to group the remembered items into their categories (e.g. cooking, travelling, driving) during recall. The findings for this group category showed that overall both nouns and verbs were better

recalled in this condition compared to the no-categorical instructions condition, however there was no effect of encoding modality for neither nouns nor verbs. The authors concluded that modality specific encoding does not benefit categorical information more than verbal encoding does. In the case of nouns, modality specific encoding even reduced category performance compared to verbal encoding. It is important to note however, that in the condition in which participants were not given any information about categorical lists, enactment encoding significantly facilitated performance for the verbs but not nouns.

In a follow up study, Engelkamp et al. (1991) found that compared to verbal encoding, enactment increased memory as tested in free recall for pairs of verbs but not pairs of nouns. They also examined cued recall whereby participants were given one word of the pair and were asked to recall the second word. Their findings show that enactment encoding impaired cued recall for nouns but not verbs. They suggested that enactment impairs relational information and that this effect is more prominent for nouns since verbs already provide very minimal relational information (Engelkamp et al., 1991).

To summarise, the studies that have examined separately memory for actions and objects show that performance for nouns was significantly higher than verbs, in all conditions and in both papers (Engelkamp et al., 1990; Engelkamp et al., 1991). However, these studies also show that it is the action verbs that mainly benefit from enactment encoding. Nevertheless, they also show a greater cost for verbs compared to nouns when examining relational information under enactment. Engelkamp et al. (1991), explain their findings based on the item-order hypothesis; they suggest that verbs exhibit greater enactment advantage than nouns do, because they are initially more abstract as concepts, so they become more concrete through enactment. Thus, they have more to gain than nouns do from physical performance. According to the authors (Engelkamp et al., 1990), the abstract verb becomes more concrete by physically performing it and thus enactment provides excellent item-specific information. According to these authors, objects naturally provide very good item information and therefore enactment has little to offer (Engelkamp et al., 1990).

1.5.2.2 Action-Object memory at recall

Additional evidence that enactment may affect differently memory for actions and objects comes from post-hoc analysis of action-object phrases in enactment recall. For example, in the enactment at recall study by Koriat et al. (1990) mentioned above, the authors also analysed the results separately for each sentence component (i.e. for actions and objects) using a serial position procedure. In other words, each response was compared to the same position in the original list. Instances in which only one component was recalled (either action or object) per sentence were excluded so that an even number of actions and objects were analysed. Their findings indicated that overall, in both verbal and enactment recall, objects were better recalled than actions. Enactment at recall led to better memory for actions and objects, however this effect was more prominent for the actions.

Further indications that enactment may specifically benefit action memory comes from the study by Yang, et al. (2014). In this study participants read instructions involving action-object phrases for later implementation while engaging in a series of distractor tasks (verbal and motor distractors). At the end of each trial there was a 1 second delay after which participants were asked to either verbally recall or perform the studied instructions. They found that although the distractor tasks impaired performance for both verbal and enactment recall, the enactment over verbal recall superiority remained evident across all distractor conditions. However, in a post-hoc analysis they found that this enactment effect was driven by the action verbs while there was no significant difference between enactment and verbal recall for the objects.

As in the studies that examined separately action and object memory at encoding, studies at enactment recall also show that order information is superior for objects than for actions. For example, Koriat et al. (1990) also looked at order memory for actions and objects by comparing the instances that objects and actions were recalled in the correct position. They found that order memory for objects was greater than order for actions in both verbal and enactment recall. This finding is consistent with the conclusions drawn by

Engelkamp et al. (1991) suggesting that actions (verbs) do not reinforce relational information. (see above). Additionally, in their second experiment, Koriat et al. (1990) found that memory for both objects and actions was impaired when the recall cue did not correspond to the actual recall mode, yet this effect was again more evident for the actions. Furthermore, Engelkamp and Zimmer (1995) found that presenting distractors (words similar to targets) during a recognition test impaired to a greater extent memory for actions compared to memory for objects under enactment but also verbal encoding. Together, these findings suggest that compared to objects, actions are more susceptible to interference (Engelkamp & Zimmer, 1995; Koriat et al., 1990) and their enactment benefit heavily depends on contextual information.

1.5.2.3 Summary

Overall, the studies that have examined enactment effects separately for actions and objects suggest that memory for objects is superior to memory for actions, across different studies and experimental manipulations. However, these studies also suggest that actions benefit to a greater extent from enactment than objects do, both during encoding and recall. Nevertheless, enactment seems to hinder relational and categorical information for actions, more so than it does for objects. Hence, it seems that compared to objects, action representations are more stable but less flexible under enactment. This is also supported by Koriat et al.'s (1990) finding that when participants were tested in the opposite mode than they expected, their performance was impaired to a greater extent for the actions than for the objects. Therefore, this may suggest that physical performance (or the intention of it), concretises actions, offering more stable and specific action representations through the realisation of action. However, this concreteness offered by enactment, also makes memory for verbs less adaptive and flexible compared to memory for objects. Performance for objects seem to already be superior to actions in all studies reported in this section both in terms of performance rates but also in terms of relational and order information. Thus, physical performance does not seem to add much benefit to memory for objects.

This section provides evidence that the enactment effect is driven mainly by superior performance for actions. The majority of the literature traditionally examines enactment for whole action-object phrases and thus the effects of physical performance on the two different categories of stimuli (actions vs objects) have not been fully explored. A closer inspection of the evidence however, shows that it is specifically the actions that benefits from physical performance. This implies that the enactment effect relies on motor processes, although the exact mechanisms and the relationship between motor and cognitive systems under this paradigm remain relatively unknown.

1.5.3 Conclusions and scope

In order to gather further evidence for the one-component hypothesis and gain an understanding of the motor processes underlying enactment, a number of factors must be considered; first, it should be clarified whether action during presentation of instructions draws upon the same mechanisms as action at recall. Second, it should be determined whether enactment enhances memory for whole action-object phrases or if it benefits specifically memory for the motor elements of these phrases. This is a crucial question in understanding the processes underlying enactment (and the type of information processed by the motor store), yet it has not been addressed directly. Another issue for further exploration is whether enactment in WM is consistent with the item-order hypothesis as discussed above. Furthermore, it has been found that enactment hinders order information for action-object phrases but it is not clear whether this effect is specific to motor actions per se. For instance, the individual effects of enactment for item and order memory specifically for the motor actions have not been examined yet. Finally, in order to develop a unified framework for the enactment effect and its underlying mechanisms, the aforementioned issues should be explored from a developmental standpoint. In other words, it should be determined whether the enactment effects at encoding and recall and the type of information benefiting from enactment, remain stable across development.

1.6 Summary and aims of current project

Enactment is a method used to study action/motor memory. Its effects have been predominantly investigated in long-term memory and less so in the context of working memory. The WM model, by Baddeley (1986), does not account for action processing within any of the WM subsystems. According to the attention model by Norman and Shallice (1980) actions are perceived as automatic schemas that operate mostly in a low-level function that does not require attention or cognitive effort. However, partial evidence suggests that action memory, as studied in immediate retrieval, may draw upon WM resources, such as the central executive. As it stands, it is not clear whether action/motor memory is an independent system that feeds information into WM or whether it is a part of the WM system as proposed by Jaroslawska et al. (2018). Although the present project does not have the intention or capacity to answer this question in full, the aim of this thesis is to better understand the cognitive mechanisms of action as part of an active online memory system.

In order to do so, the experiments reported here examine separately action and object memory. As mentioned above, evidence from the literature mostly suggest that enactment specifically benefits memory for the actions, although there are exceptions (see Gathercole et al., 2008). Distinguishing the information that is affected more by enactment, and whether this is subject to developmental changes, is a crucial step in understanding this system and how it operates. A further question is whether action memory develops with age, like WM, or whether it remains constant throughout development. Answering this question will further broaden the understanding of this system and, perhaps, will offer some insights into the relationship between action and WM.

Therefore, the first experimental chapter (Chapter 2) presents two experiments that aimed to examine the different effects of enactment memory for actions and for objects in children (Experiment 1) and in adults (Experiment 2). This study examined enactment vs verbal memory at both encoding and recall.

Chapter 3 reports two experiments that manipulated enactment at encoding only, while retrieval was in orthographic form (computerised) in children (Experiment 3) and in adults (Experiment 4). In this study encoding was either enactment or verbal and recall consisted of item recognition or order reconstruction. Additional WM measures were employed in order to investigate the relationship between enactment performance and WM resources.

The final experimental chapter (Chapter 4), reports two experiments that investigated the effects of enactment and the item-order hypothesis for actions and objects at the retrieval phase in children (Experiment 5) and adults (Experiment 6). In these studies, encoding was auditory, and enactment was manipulated at recall which again involved item recognition or order reconstruction. These two experiments also employed two WM tasks aiming to further identify links between WM and enactment performance in immediate memory recall.

The general discussion (Chapter 5) summarises the findings from the six experiments and draws further conclusions about the nature of the enactment effect, and its relationship to WM, based on the results obtained and the literature. In addition, the current investigation raises a number of questions relating to the nature of action memory and suggests future directions in order to further examine these issues.

2 Chapter 2: Enactment effects manifest in a different manner for actions and objects in children and adults.

2.1 Introduction

When asked to memorise a set of instructions such as “lift the ball” or “tap the table” participants’ performance is typically better when they physically carry out these action phrases as opposed to verbally repeating them (Engelkamp & Zimmer, 1995). This phenomenon is known as the enactment effect or Subject Performed Task (SPT) effect (Cohen, 1981; Engelkamp et al., 1994). Several studies have shown a memory advantage of enactment over verbal repetition at the encoding phase (Engelkamp, 1998; Kormi-Nouri, Nyberg & Nilsson, 1994) as well as during the recall phase following verbal instructions in both adults (e.g. Yang, Gathercole & Allen, 2014) and in children (e.g. Gathercole et al., 2008). The enactment effect in following instructions has been found both in immediate memory recall (e.g. Allen & Waterman, 2015; Yang, Gathercole & Allen, 2014) as well as in long term retrieval (e.g. Engelkamp & Zimmer, 1994). The ability to temporarily maintain, follow and execute instructions is closely linked to Working Memory (WM), a limited capacity cognitive system that temporarily holds and manipulates information. Accumulating evidence suggests that, compared to verbal learning, physically enacting instructions leads to superior memory performance even when participants engage in concurrent distractor tasks aimed to disrupt WM processing (Yang, Allen & Gathercole, 2016). This indicates that action memory might not be solely dependent on WM resources (Yang, Gathercole & Allen, 2014). Given that enactment can facilitate memory and successful implementation of instructions beyond WM limitations, it is viewed as a potential educational tool to improve learning within the classroom. Considering this, it is important to understand the underlying mechanisms of the enactment effect.

2.1.1 Enactment in working memory in adults and children

In studies that involve enactment, participants typically listen to a set of sentences that include a verb and an object (e.g. throw the ball) and are then asked to perform these actions either at the encoding phase (enactment encoding with verbal retrieval) or at the recall phase (verbal encoding with enactment retrieval). The interaction between enactment/verbal encoding and enactment/verbal recall has been also examined. As mentioned in Chapter 1 (section 1.3.1), Allen and Waterman (2015) investigated the effects of enactment compared to verbal learning during encoding as well as retrieval in young adults. They created four conditions by crossing enactment or verbal encoding with enacted or verbal recall. Their findings indicated an overall benefit of enacted recall, with participants recalling a significantly greater number of items when recall was through enactment independently of encoding mode (enactment or verbal). This finding suggests that processing during encoding was dependent on subsequent recall mode. In other words, it appears that participants encoded the information in a different manner when they knew they will be asked to recall it through enactment. This fits with the assumption that enactment at recall triggers additional spatial-motor processing during the encoding of information, in other words that enactment recruits additional spatial-motor networks that facilitate performance (Koriat, Ben-Zur & Nussbaum, 1990). Similar studies with children have also observed a benefit of enactment at recall (Waterman et al., 2017) as well as enactment at encoding (Jaroslawska et al., 2016) but not additive enactment benefits of enactment encoding and enactment recall.

For example, Waterman et al. (2017) used the Allen and Waterman (2015) paradigm, to investigate enactment vs verbal encoding and recall using the same instructions (see Chapter one, section 1.3.1 for details) in children. Participants age ranged from 6 to 10 years old, with a mean age of 8 years, 4 months. During the encoding phase participants either passively listened to the instructions given by the experimenter (verbal encoding, no-enactment) or they performed each instruction immediately after verbal presentation

(enactment). In both encoding conditions there was a 2 seconds delay between the presentation of each phrase during which participants either performed the instructions (enactment encoding) or waited for the next phrase (no-enactment encoding). Their results showed a benefit of enactment recall (independently of encoding mode) but enactment at encoding seemed to hinder performance compared to verbal encoding. In the second study reported in this paper, enactment encoding was replaced by observation whereby children observed the experimenter performing the actions during encoding. The no observation encoding was identical to the no enactment encoding condition in Experiment 1. Replacing enactment with observation enhanced children's performance as observation encoding lead to superior memory performance compared to no-observation. As in Experiment 1, enactment recall was superior to verbal recall. Finally, their third experiment was identical to Experiment 1, but this time the action words in the instructions were reduced from six to two (following the paradigm established by Gathercole et al., 2008 and Jaroslawska et al., 2016). They found that reducing the actions to be performed to two distinct motor movements, lead to enactment encoding benefits. As with their previous experiments, enactment recall was also superior to verbal recall. The authors argued that including six motor actions in the instructions increased the task demands leading to poorer enactment encoding performance. They concluded that by reducing the motor actions to two items (Experiment 2b) or by replacing enactment encoding with observation (Experiment 2a), they reduced the task demands thus finding an enactment encoding benefit.

2.1.2 Motor store and Working Memory in children and adults

Although the precise underlying cause of the enactment effect is not fully established, it is generally believed that performing physical actions, or planning to do so, generates action-motor plans which are held in some form of a temporary motor store (Engelkamp & Zimmer, 1984; Jaroslawska et al., 2016; Zimmer & Engelkamp, 1985). According to the one-component hypothesis, this is a system that temporarily holds and manipulates temporal,

spatial and motoric action information which in turn affects in some way the WM system (Jaroslawska et al., 2016; Jaroslawska et al., 2018) (for more details see Chapter 1, section 1.4.3). Nevertheless, it is unclear whether the motor store processes action events as a whole (e.g., actions, objects, object features, and other spatial information) or whether it is specifically dedicated to motor actions per se.

Consistent with the one-component hypothesis, if both enactment encoding and enactment recall rely on the motor store, then enactment at recall should not provide any additional benefits if the information has already been enacted at encoding. This is because the motor information would have been already recorded in the motor store during the encoding phase (Allen & Waterman, 2015). Indeed, most recent findings with adults and children have not found additional benefits when both encoding and recall is through enactment (Waterman et al., 2017; Allen & Waterman, 2015, Jaroslawska et al., 2016).

Additional evidence to support the idea of an independent motor store come from studies that used common WM concurrent distractor tasks such as articulatory suppression or spatial tapping during the verbal encoding phase of instructions (i.e. auditory, reading). When participants engage in distractor tasks during encoding, recall performance is impaired under all recall conditions (i.e. verbal recall, enactment recall) however the enactment recall advantage remains intact (Yang et al., 2014; Yang et al., 2016). These findings led Yang et al. (2016) to suggest that performance after enactment does not depend on WM abilities.

However, while in adult samples enactment performance does not seem to be strongly dependent on WM (Yang, Gathercole & Allen, 2014), studies with children suggest a stronger involvement of WM in enactment performance (Waterman et al., 2017). For example, Gathercole et al. (2008) investigated the effects of enactment at recall in 24 five-year-old children. Participants listened to a set of instructions and were then asked to either verbally recall or enact them using the objects provided (for details about the methodology in this study see Chapter 1, section 1.3.1). Children were twice as accurate in the enactment recall condition compared to verbal recall. Furthermore, enactment, but not verbal, performance was strongly associated with WM performance as measured by the FDR and

the BDR tasks which tap at the phonological loop and the central executive respectively (Gathercole et al., 2008). Similarly, Waterman et al. (2017), also found a strong link between WM measures and enactment performance. In this study (discussed above), participants additionally completed three WM tasks namely, the FDR, BDR and the Corsi task. The latter is a visuospatial WM measure in which involves participants memorising in serial order spatial locations. Waterman et al. (2017) found strong correlations between all WM measures and enactment and verbal encoding and recall as well as demonstration encoding (with a few exceptions). Overall, performance in enactment seem to correlate strongly with BDR, which is a central executive measure, as well as Corsi (except for enactment encoding in experiment 1). The authors concluded that WM plays an important role in enactment performance in children.

Taken together, these findings suggest that in adults, the benefits of enactment stem from the reduced need to use WM resources while in children WM predicts the extent to which participants will benefit from enactment. This in turn suggests that enactment may operate in a different way in adults and children. Thus, examining enactment from a developmental perspective, appears to be a way to further understand this effect.

Finally, Waterman et al. (2017) suggested that their findings are in accordance with the one-component hypothesis as enactment at both encoding and at recall did not lead to superior performance compared to enactment at one stage (encoding or recall). They also drew on the motor store hypothesis suggesting that in children, as in adults, there is a memory benefit of motor processing leading to superior enactment performance compared to verbal learning. These results support the one-component hypothesis suggesting a motor store involvement in action memory throughout development. However, the motor store's exact relationship to WM might be evolving with age given that, compared to adults, children's' enactment performance is more closely linked to WM capacity.

2.1.3 Actions vs. Objects- Developmental Differences

Although the enactment memory advantage for action-object phrases is well documented in the literature, it is unclear whether enactment facilitates memory universally or whether this effect is localised to the type of information to be remembered. If the recruitment of motor action plans is indeed the underlying cause of this effect, then it is reasonable to assume that enactment might benefit more, or indeed only, memory for verbs as opposed to other sentence elements (such as nouns) since it is the action itself that is enacted. For example, it has been suggested that memory representations for action events and objects are partially independent of each other as they consist of different representational subunits containing different information (Engelkamp & Zimmer, 1984). Partial evidence for this assumption comes from a study by Engelkamp, Mohr and Zimmer (1990) who studied separately lists of verb pairs (actions) and noun pairs (objects) under enactment and verbal encoding in young adults. While they found that nouns were overall better recalled than verbs, only memory for the verb pairs benefited from enactment. However, the verbs and nouns were not integrated into action-object pairs in this previous study, but rather they were studied in two separate lists. Enactment in the literature has been predominantly studied using action-object pairs and therefore it would be more appropriate to study the different effects of actions and objects within that paradigm. Finally, Engelkamp et al. (1990) examined enactment only at the encoding phase while most studies of enactment effects on immediate recall have focused on enactment recall.

Additional evidence that actions and objects are affected in a different manner by enactment was provided by Yang et al. (2014) who examined enactment and verbal recall after verbal encoding with concurrent distractor tasks. Although they found an enactment recall advantage, a post-hoc analysis revealed that this effect was driven by the action verbs. However, similar studies with children show a different pattern. For example, Gathercole et al. (2008) found that children's performance in enactment recall was twice as accurate for all the sentence features (i.e. objects, actions, objects' colours). Further,

Gathercole et al. (2008) also found a link between enactment and WM performance which is not necessarily consistent with adult findings (e.g. Yang et al. 2014). Taken together, these results imply that, compared to adults who seem to benefit from enactment only for actions, children benefit from enactment more universally (i.e. enactment benefits both action and object memory), however, this comes at a greater WM cost. A question of interest is whether this effect reflects developmental changes in the motor store-WM relationship.

2.1.4 The present study

The findings from the aforementioned studies, suggest that enactment benefits might differ for children and adults, as among children enactment seems to benefit all sentence elements while in adults the enactment benefit is driven by an effect that is limited to the action words. However, these assumptions are based on a post-hoc review of the evidence and the effects of enactment for different sentence elements are yet to be examined directly. Therefore, the present study aimed to explore this idea further by examining separately action and object memory for integrated verb-noun pairs under enactment or verbal encoding and enactment or verbal retrieval in two experiments involving either children (Experiment 1) or adults (Experiment 2). This enabled the examination of developmental differences in the manifestation of the enactment effect. The central aim was to investigate how enactment independently affects memory for actions and objects under all enactment encoding and retrieval conditions. Testing separately memory for objects and actions under enactment will clarify the type of information processed by the motor store. If enactment at encoding or retrieval leads to better memory only for the actions (verbs), then this would suggest that the underlying mechanism that gives rise to the effect relies on purely motoric processing. If, however, enactment leads to better memory for actions as well as objects then that would suggest that the benefits of enactment, as mediated by the motor store, go beyond purely motoric processing

The secondary aim of the current study was to examine whether these effects remain stable across development since there are mixed findings in the previous literature. Examining separately actions and objects memory under enactment in children and in adults allows the exploration of the type of information processed by the motor store and whether its processes are susceptible to developmental changes. For instance, if enactment leads to better memory for actions and objects in children but only to actions in adults as previously implied, then that would suggest that the role of the motor store (or its dependence to WM) changes with age. Therefore, Experiment 1 examined enactment benefits for actions and objects in children with the aim of identifying if memory for actions and objects within action-object pairings is affected equally by enactment. Based on previous findings, it was expected that a memory advantage for actions and objects after enactment encoding as well as after enactment retrieval would be observed. Experiment 2 aimed to test for developmental changes with regards to the enactment benefit, by examining how enactment affects separately action and object memory in adults. Based on previous research, it was hypothesised that enactment encoding, and enactment recall would both benefit enactment performance for the actions in adults. No differences were expected with regards to object memory in adults between verbal and enactment conditions. This prediction was based on previous research suggesting that memory for nouns has little to gain from physical performance (Engelkamp et al., 1990).

2.2 Experiment 1

Following the approach of Allen and Waterman (2015) the present experiment employed a similar design to test all four possible combinations of enactment vs. verbal encoding and enactment vs. verbal retrieval modes. Crucially, this study also included the novel manipulation of probe type so that at the end of each trial participants had to recall either just the actions or just the objects presented during encoding. This enactment vs verbal memory task for actions vs objects was named Instructed Action Feature Task (IAFT). Based on the literature, it was expected that enactment at retrieval would facilitate memory for both actions and objects. Consistent with the one component hypothesis, if the benefits of enactment retrieval rely on the same mechanism as enactment encoding, then one would also expect a benefit of enactment encoding for actions and objects, but not additive effects of enactment encoding and enactment retrieval. Finally, the age group of the participants was chosen after pilot work indicated that eight years of age was the youngest age at which participants could fully understand the instructions and procedure.

2.2.1 Method

Participants

Twenty-four Year 3 students ($Mean_{age} = 8.7$ years, $SD_{months} = 3.35$) were recruited from local schools. Students took part only on receipt of full, informed, parental consent. Participants also gave verbal consent prior to their sessions. They were tested in a quiet area of their school and they were given stickers for their participation. Students took part in the study on two separate sessions lasting 40 minutes each approximately 1 week apart. Ethical approval for this study was secured from the appropriate institutional review board – the University Of Bristol Faculty Of Science Human Research Ethics Committee.

Material

Instructed Action Feature Task (IAFT)

The stimuli used in this task were 9 foam objects (approximately 5cm x 4cm each) in the shape of numbers 0 to 8 (see fig 2.1) and eight verbs. These objects were chosen after careful consideration; numbers are shapes familiar to children but at the same time abstract enough to avoid any obvious semantic associations or familiar pairings between verbs and objects. The 9 foam objects were divided into two sets; objects 1 to 8 formed one set and object 0 the other. The zero shaped object was used separately as a neutral object to perform the actions on in the enactment recall conditions. The 8 verbs indicated the actions to be performed on the 8 foam objects. The action verbs used in this study were chosen from a larger pool of verbs on the basis of their distinctiveness after pilot work. Those verbs were “*push, shake, tap, drop, turn, rub, squeeze, lift*”. The 8 verbs and the 8 numbers created a total of 64 action-object pairs. A trial consisted of either 3 or 4 action-object pairs. This span length combination was deemed as the most optimal for this age group based on the literature and on pilot work. The pairs were pseudorandomised to ensure that no action or object appeared twice in the same trial or in the exact same position in the previous or next trial. In total 4 blocks were created, each with a unique combination of object-action pairs per trial. A group of 16 trials created a block. Each action-object pair appeared once in each block of trials and a total of 3 or 4 times across all blocks. The presentation order of these blocks remained fixed across all participants while the order of the encoding-recall conditions was counterbalanced across these blocks. The four encoding-retrieval conditions were presented in fixed pairs according to the encoding condition. Thus, participants completed Enactment encoding - Enactment retrieval (EE) and Enactment encoding- Verbal retrieval (EV) in one session, and Verbal encoding-Enactment retrieval (VE) and Verbal encoding-Verbal retrieval (VV) in the other session. The task was created and presented in Microsoft PowerPoint.



Figure 2.1. The objects used in the experiment

Design

The instructed action task employed a 2x2x2x2 repeated measures design manipulating encoding mode (verbal vs. enactment), retrieval mode (verbal vs. enactment), probe type (action vs object) and trial length (three or four sentences per trial). The dependent variable for the instructed action task was recall accuracy and was manifested in two levels; the number of items recalled correctly, and the number of items recalled correctly in the correct order (i.e., free and serial recall). According to a substantial body of literature (e.g. Engelkamp & Dehn, 2000; Schult, Stulpnagel & Stephens, 2014), enactment is thought to enhance item memory (memory for individual stimuli) but not relational information (for example serial order) (for further details see Chapter 1, section 1.5.1). In light of this, and since this was an exploratory study, it was deemed appropriate to employ both scoring methods in order to capture any potential enactment benefits that might not be apparent in serial recall. Therefore, although this was primarily a serial recall task, free recall data were also recorded and analysed.

Procedure

Participants faced towards a table on which the foam shape numbers were present at all times. In each session participants completed 2 blocks of 16 trials each. Participants completed a set of five practice trials before the presentation of each block. Each trial consisted of three or four action-object pairs (arranged pseudo-randomly). Each pair included an action verb and a number object (i.e., squeeze the 5, drop the 1, push the 4). Pairs were auditorily presented at a rate of 1 per 1200 milliseconds. The recorded voice was

modified so that auditory presentation length for each verb and each number lasted precisely 600 milliseconds each. There was a 4 seconds delay between the presentation of each action-object pair during which participants either verbally repeated the instruction or enacted it, depending on the encoding mode. After each trial participants saw an image on the screen that indicated retrieval for either the objects (see Figure 2.2) or the actions (see Figure 2.3) presented in that trial (ordered pseudo-randomly). Depending on the retrieval mode (enactment or verbal) participants retrieved the items either through enactment or verbally. Participants were instructed to retrieve the items in the correct order. The foam shapes were randomly re-arranged after every 4 or 5 trials. The experimenter sat on the left-hand side of the table and recorder participants' responses manually using a laptop.



Figure 2.2. Image presented to participants probing object recall.



Figure 2.3. Image presented to participants probing action recall.

Procedure for the four conditions of the IAFT

Enactment- Enactment (EE)

Prior to the beginning of the presentation of this block participants were asked to “do what they hear” during the four seconds interval between the presentation of each action-object pair. At the end of the trial participants had to re-enact the actions using the zero shaped foam object if the action image was presented or point at the objects used if the number image was presented.

Enactment- Verbal (EV)

The encoding procedure was identical to the above condition. That is, participants had to enact the auditory items presented during encoding. However, during retrieval participants had to verbally retrieve the actions if the action image was presented or verbally retrieve the numbers if the number image was presented.

Verbal – Enactment (VE)

Prior to the beginning of the presentation of this block participants were asked to “verbally repeat what they hear” during the four seconds interval between the presentation of each action-object pair without moving their hands. During retrieval, participants had to enact the actions using the zero shaped foam object if the action image was presented or point to the objects if the number image was presented.

Verbal- Verbal (VV)

The encoding condition was identical to the above condition. Participants listened to the auditory items and they were asked to “repeat what they hear”. At the end of the trial participants had to verbally retrieve the actions if the action image was presented or verbally retrieve the numbers if the number image was presented.

Short Term Memory

Participants completed a total of four short term memory (STM) tasks; two STM tasks with digits (STMD) and two STM tasks with verbs (STMV). Students completed one STMD and one STMV at the beginning of the first assessment session and one STMD and one STMV task at the end of the second session (order was counterbalanced so that participants who completed the STMD task first on day 1 completed it second on day 2). The STMD tasks

presented participants with lists of numbers (ranging from 1-8) which they were then asked to recall in the correct order; the STMV tasks sampled the set of verb items used in the instructed action task and similarly required serial ordered recall. Therefore, both types of STM task were constructed using the material employed in the IAFT (numbers and verbs). In all other respects the two types of task involved the same procedure: trials began at a span level of two items per trial and increased progressively (with two trials at each span level). Each item was pre-recorded and presented auditorily at a rate of 1 item per second with no additional time interval between items and recall was self-paced. The task ended when the participant failed to recall all the items in correct order on both trials at a given span level. The dependent variable extracted, was serial recall accuracy, calculated using partial credit scores (Conway et al., 2005). This is the sum of all trials (average performance per trial) per participant. This was then averaged across the two versions of each task type (i.e., average STMD and average STMV performance).

2.2.2 Results

The descriptive statistics for free and serial recall can be seen in Tables 2.1 and 2.2 respectively.

Table 2.1. Means and standard deviations reflecting proportion correct in each of the encoding and retrieval conditions for trial length 3 and 4 under free recall scoring.

			Free Recall			
			Actions		Objects	
Encoding	Retrieval	Trial Length	Mean	SD	Mean	SD
E	E	3	0.78	0.12	0.91	0.10
E	E	4	0.63	0.10	0.84	0.11
E	V	3	0.76	0.11	0.93	0.09
E	V	4	0.64	0.14	0.83	0.14
V	E	3	0.80	0.13	0.84	0.12
V	E	4	0.65	0.14	0.78	0.12
V	V	3	0.72	0.15	0.78	0.14
V	V	4	0.63	0.19	0.75	0.15

Note: E=Enactment, V= Verbal.

Table 2.2. Means and standard deviations reflecting proportion correct in each of the encoding and retrieval conditions for trial length 3 and 4 under serial recall scoring.

			Serial Recall			
			Actions		Objects	
Encoding	Retrieval	Trial Length	Mean	SD	Mean	SD
E	E	3	0.36	0.22	0.52	0.33
E	E	4	0.20	0.14	0.31	0.26
E	V	3	0.30	0.22	0.61	0.33
E	V	4	0.20	0.13	0.38	0.29
V	E	3	0.39	0.26	0.52	0.28
V	E	4	0.24	0.19	0.35	0.27
V	V	3	0.33	0.23	0.47	0.31
V	V	4	0.20	0.15	0.39	0.30

Note: E=Enactment, V= Verbal.

An initial analysis of variance revealed that participants recalled significantly more items in free recall than serial recall for both actions, $F(1, 23) = 474.546$, $p < .001$, $\eta_p^2 = .954$ and objects $F(1, 23) = 176.814$, $p < .001$, $\eta_p^2 = .885$. Additionally, a one-factor analysis of variance revealed that participants recalled significantly more objects than actions in both free recall, $F(1, 23) = 96.246$, $p < .001$, $\eta_p^2 = .807$ and in serial recall, $F(1, 23) = 28.485$, $p < .001$, $\eta_p^2 = .553$.

Free Recall

Initially, the data were analysed using a 2x2x2x2 (probe type x encoding mode x recall mode x trial length) repeated measures analysis of variance. This revealed a significant interaction between probe type and encoding mode $F(1, 23) = 10.682$, $p = .003$, $\eta_p^2 = .317$. Thus the data were split according to probe type for further analysis in order to investigate the different effects of encoding mode for action and object recall.

A 2x2x2 (encoding mode x recall mode x trial length) analysis of variance for memory for actions revealed a significant main effect of trial length $F(1, 23) = 42.748$, $p < .001$, $\eta_p^2 = .650$ but trial length did not interact significantly with any other factor. Similarly, a 2x2x2 (encoding mode x recall mode x trial length) analysis of variance on the object recall data revealed a significant main effect of trial length $F(1, 23) = 25.195$, $p < .001$, $\eta_p^2 = .523$. However again, no interactions between trial length and other factors were significant. Given that there were no significant interactions with trial length for the objects or the actions, it was decided to collapse across trial lengths in further analysis. Further, two 2 (encoding) x 2 (recall) analyses of variance were conducted separately for actions and objects (see table 2.3 for the results).

Serial Recall

Initially, a 2x2x2x2 (Probe x Encoding mode x Retrieval mode x Trial length) repeated measures analysis of variance showed a significant interaction between probe type and

retrieval mode $F(1, 23) = 5.778$, $p = .025$, $\eta_p^2 = .201$ but no interactions with trial length were significant. Thus, the data were split according to probe type but collapsed across trial length for further analysis in order to investigate the different effects of enactment for actions and objects. A 2x2 (encoding mode x retrieval mode) repeated measures ANOVA was performed separately for each probe (actions, objects) in serial and free recall. The results can be seen in Table 2.3 below.

Table 2.3. Effects of encoding and retrieval mode for actions and objects in free and serial recall.

	Actions				Objects			
Free Recall	F	df	p	η^2	F	df	p	η^2
Encoding mode	0.006	23	.940	< .001	25.128	23	<. 001	.522
Retrieval mode	2.887	23	.103	.112	1.349	23	.257	.055
Encoding x Retrieval	2.607	23	.120	.102	1.998	23	.171	.080
Serial Recall								
Encoding mode	0.792	23	.383	.033	0.109	23	.744	.005
Retrieval mode	5.612	23	.027	.196	1.204	23	.284	.050
Encoding x Retrieval	0.444	23	.512	.019	1.239	23	.277	.051

As can be seen in Table 2.3, enactment at encoding did not benefit memory for actions in free recall (see Figure 2.4). It did however lead to greater memory performance for the objects in free recall and this effect was independent of retrieval mode (see Figure 2.5). Enactment retrieval in serial recall lead to greater performance for action (see Figure 2.6) but not objects (see Figure 2.7).

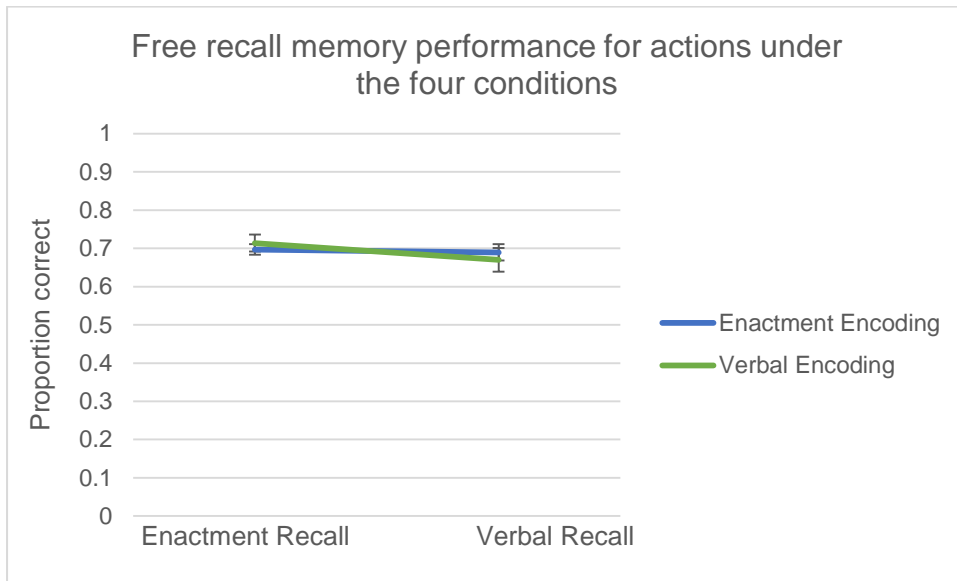


Figure 2.4. Performance for the actions in free recall under the four encoding-retrieval conditions. Error bars represent the standard error of the mean.

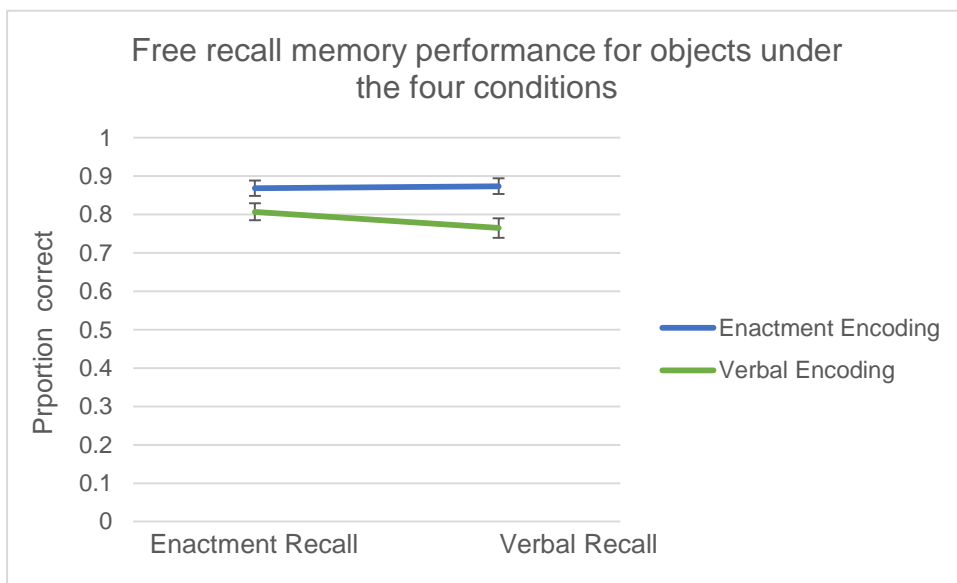


Figure 2.5. Performance for the objects in free recall under the four encoding-retrieval conditions. Error bars represent the standard error of the mean.

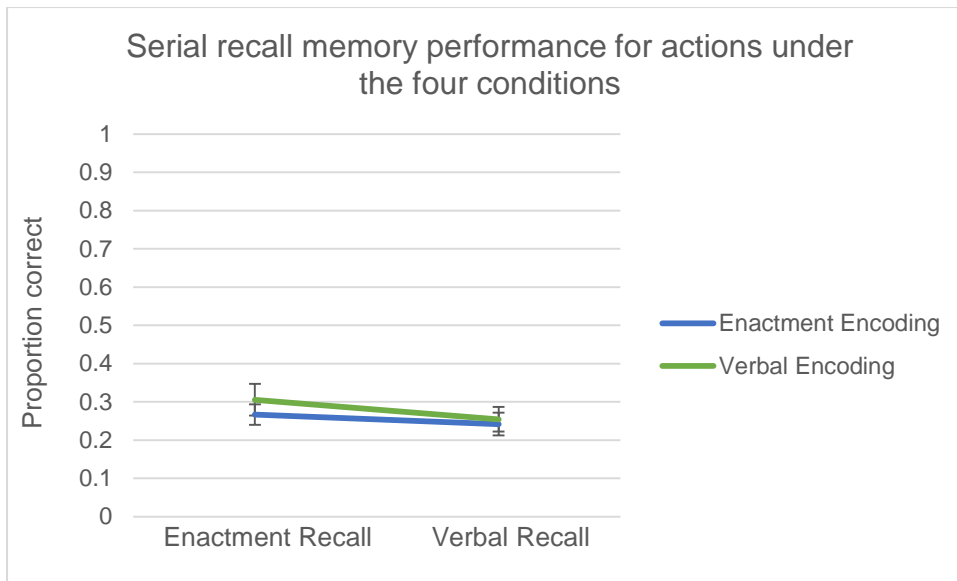


Figure 2.6. Performance for actions in serial recall under the four encoding-retrieval conditions. Error bars represent the standard error of the mean.

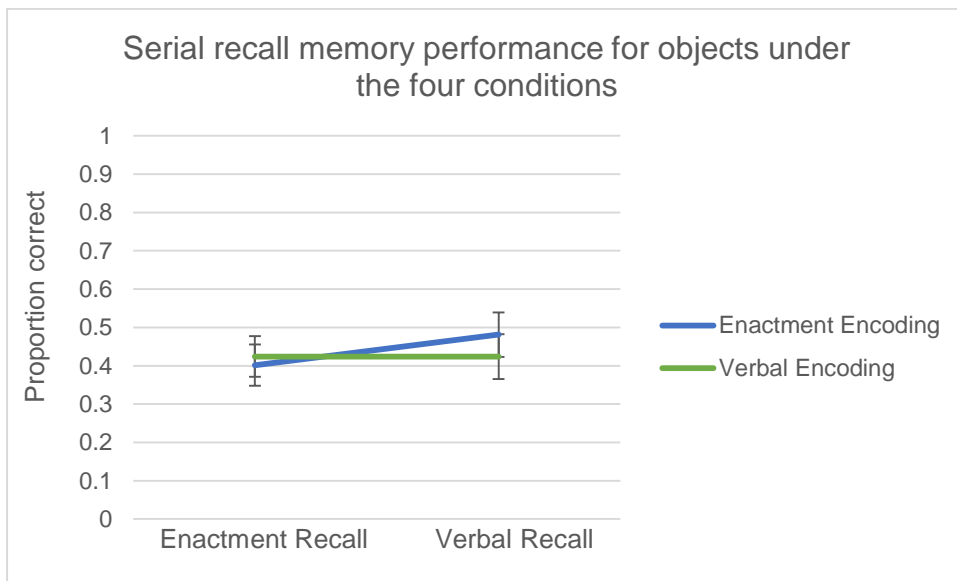


Figure 2.7. Performance for the objects in serial recall under the four encoding-retrieval conditions. Error bars represent the standard error of the mean.

Short Term Memory

Overall, participants performed significantly better in the STMD than the STMV tasks, $F(1, 23) = 26.764$, $p < .001$, $\eta_p^2 = .538$. However, since the correlation between the partial credit

scores for the two STM tasks was highly significant, $r(24) = .701$, $p < .001$ it was decided to combine the two measures for further analysis.

A subsequent correlational analysis between STM and IAFIT serial performance for actions and objects revealed that STM capacity was highly correlated with IAFIT performance under verbal encoding but not enactment encoding (Table 2.4). As the data show, performance in the encoding enactment conditions was independent of short-term memory capacity.

Table 2.4. Correlations between STM capacity and memory performance in the four conditions for actions and objects.

STM and Probe	Condition			
	EE	EV	VE	VV
STM and actions	.29	.31	.59**	.55*
STM and objects	.12	.10	.44*	.18

Note: * Significant at the .05 probability level. ** Significant at the .01 probability level.

2.2.3 Discussion

The central aim of Experiment 1 was to examine separately children's memory for actions and objects under enactment or verbal encoding and retrieval. It was hypothesised that children would benefit from both enactment encoding and retrieval for actions as well as objects and these effects would be more prominent in free recall since enactment hinders order information. The results from this study showed that children's memory for actions benefited from enactment retrieval in serial recall and that their memory for objects benefited from enactment encoding in free recall. These results will be discussed in turn below.

Independently of encoding mode, enactment at retrieval facilitated memory for actions as tested in serial recall. This benefit of enactment retrieval in children is broadly consistent with previous research (Waterman et al., 2017; Jaroslawska 2016), but the finding that this effect is specific to retrieval of actions rather than objects in serial, but not free recall is novel.

Enactment retrieval is thought to enhance memory performance by promoting the formation of motor action plans during the encoding phase. In other words, when participants know they will have to perform the actions during recall, and even if presentation is verbal, they encode that information in a motor manner for later execution (Koriat et al, 1990). Our findings provide further support for this assumption by showing that it was specifically the action memory that benefited from enactment recall.

This suggestion is consistent with the lack of a reliable correlation between enactment encoding and STM capacity observed in the data, which suggests that participants did not use verbal memory strategies to any meaningful degree during enactment encoding of the actions. However, these results are not entirely consistent with those of Gathercole et al. (2008) who observed enactment recall benefits for all instruction elements (i.e. actions, objects, colours of stimuli). An important difference between the Gathercole et al. (2008) study and this experiment is that in the current study participants were asked to recall either the objects or the actions rather than the action-object pairing. In the case of enacted action retrieval participants were asked to retrieve the actions by performing them on a neutral object and in the case of enacted object retrieval participants had to simply point at the objects. In Gathercole et al.'s (2008) study participants were asked to recall a set of instructions on the corresponding objects in the environment such that action and object information remained bound together (e.g., pick up the blue ruler and put it in the red box). These major differences in the stimuli and methodology may be responsible for these differences in the results, because Gathercole et al.'s design would have been unable to tease apart action- and object-specific effects. In contrast, the aim of this study was to explicitly study the specific effects of enactment on actions and objects separately. Therefore, isolating the information during recall was a crucial aspect of the experimental manipulation.

Contrary to enactment retrieval, enactment at encoding facilitated memory for the objects as tested in free but not serial recall. This is consistent with the literature which suggests that enactment facilitates item information in free recall or recognition (see Engelkamp & Dehn,

2000). Presumably, physically interacting with the objects during the encoding phase provided participants with additional visuospatial information that enhanced recall for the objects. However, enactment at encoding did not facilitate performance for actions in the current sample of children, which is consistent with the findings of Waterman et al. (2017, Experiment 1) but not Jaroslawska et al. (2016). Our study stimuli differed from previous research in two important ways. First, our stimuli were novel action-object phrases (e.g. squeeze the 4, tap the 7) that did not carry any semantic meaning or associations and therefore they might have been more difficult to memorise. Second, in this study, participants were asked to recall either the actions or the objects of each trial. The additional process of selectively remembering one component of the action-object pairing may have affected the way participants encoded or retrieved the information. For example, mentally separating the type of item to be retrieved may have posed a heavier load on working memory, requiring a greater involvement of executive processes.

Indeed, as discussed in the introduction of this chapter, Waterman et al. (2017) suggested that the lack of enactment encoding effects in their study reflected task difficulty; in other words, their task was too demanding for children to show any enactment encoding benefits. To test this assumption, they conducted two further studies, aiming to reduce memory demands by replacing enactment encoding with observation (observing someone else performing the actions, Experiment 2a) and by reducing the instructions' action span per trial from 6 to 2 (Experiment 2b). In both instances, children showed benefits of enactment encoding when the task was made easier by these manipulations. Therefore, it is suggested that in the current study, enactment encoding similarly posed sufficient executive demands to prevent children from exploiting the advantages of the additional spatial-motoric codes provided by enactment encoding. The assumption that the task was particularly challenging is reflected in the overall performance rates.

STM scores correlated with memory performance for the actions in the verbal encoding conditions but not in the enactment encoding conditions. This suggests that participants engaged in verbal maintenance of actions in the verbal encoding but not under enactment

encoding. IAF performance rates were similar under enactment and verbal encoding but only verbal encoding showed a correlation with STM scores. This suggests that in the enactment encoding condition, participants may have used an alternative method of retention, perhaps in motoric or mental imagery form. However, since the current study did not employ any visuospatial or mental imagery measures, no firm conclusions can be drawn on this particular suggestion.

STM scores and memory performance for the objects exhibited a similar pattern. STM did not correlate with enactment encoding but was significantly correlated with performance in the verbal encoding with enactment recall condition indicating verbal maintenance for the objects. The surprising finding was the lack of correlation between STM scores and the verbal encoding with verbal recall performance for objects. Although there is no direct explanation for this finding, this lack of correlation may reflect the lack of active verbal rehearsal for the objects. Perhaps this condition was relatively easy for the children and did not pose heavy demands on memory.

Overall, the findings from experiment 1 suggest that enactment benefits children's memory for both actions and objects but in a different manner. The current findings are not entirely consistent with the item-order hypothesis (see Introduction, section 1.4.1) which assumes that enactment benefits item memory (e.g. free recall) but not order memory (e.g. serial recall), especially for the actions. Here, it was shown that enactment enhanced memory for actions when examining serial but not free recall.

2.3 Experiment 2

The aim of Experiment 2 was to examine the effects of enactment at encoding and at retrieval separately for actions and objects in an adult sample. Comparing the two different age groups will help to shed light on the nature of the enactment effect. As mentioned above, previous research has not examined the effects of enactment for actions versus objects in this paradigm. It has nevertheless been shown that enactment benefits in adults

might be driven by greater memory for action words rather than other sentence elements (Yang et al., 2014). Therefore, based on previous evidence, an effect of enactment at encoding and recall for the actions but not the objects was expected.

2.3.1 Method

Participants

24 young adults ($Mean_{age}=22.4$ years, $SD_{months}=4.48$) took part in a one-hour long session at the University of Bristol. Participants gave their full consent in writing and verbally. They were paid £7 for their participation. Ethical approval for this study was secured from the appropriate institutional review board – the University Of Bristol Faculty Of Science Human Research Ethics Committee.

Design

The instructed action task employed a 2x2x2x2 repeated measures design manipulating encoding mode (verbal vs. enactment), recall mode (verbal vs. enactment), probe type (action vs object) and trial length (five or six sentences per trial). This trial length seemed optimal after pilot work.

Material and Procedure

Material and procedure were identical to Experiment 1, but the tasks were adapted for difficulty. The instructed action task consisted of sentences at the span levels of 5 and 6 and the STM tasks started at a span of 4 and went up to 9. Participants completed 2 STM tasks (1 with verbs and 1 with digits) at the beginning of the experiment followed by the 4 blocks of trials (one for each condition) and the other 2 STMS tasks (1 with verbs and 1 with digits) at the end. The order of the IAFT conditions and the order of the STM tasks was counterbalanced across participants. The experimenter sat on the left-hand side of the table and recorder participants' responses manually using a laptop.

2.3.2 Results

The descriptive statistics for free and serial recall can be seen in Tables 2.5 and 2.6 respectively.

Table 2.5. Means and standard deviations reflecting proportion correct performance in each of the encoding and retrieval conditions for trial length 5 and 6 under free recall scoring.

Free Recall						
Encoding	Recall	Trial Length	Actions		Objects	
			Mean	SD	Mean	SD
E	E	5	0.82	0.14	0.93	0.06
E	E	6	0.68	0.20	0.87	0.08
E	V	5	0.82	0.13	0.95	0.05
E	V	6	0.69	0.12	0.90	0.07
V	E	5	0.74	0.13	0.93	0.11
V	E	6	0.65	0.15	0.86	0.09
V	V	5	0.78	0.14	0.90	0.13
V	V	6	0.64	0.16	0.85	0.15

Table 2.6. Means and standard deviations reflecting proportion correct performance in each of the encoding and retrieval conditions for trial length 5 and 6 under serial recall scoring.

Serial Recall						
Encoding	Recall	Trial Length	Actions		Objects	
			Mean	SD	Mean	SD
E	E	5	0.51	0.27	0.60	0.24
E	E	6	0.30	0.24	0.41	0.22
E	V	5	0.45	0.28	0.72	0.18
E	V	6	0.30	0.18	0.51	0.20
V	E	5	0.33	0.14	0.72	0.23
V	E	6	0.22	0.15	0.54	0.24
V	V	5	0.35	0.25	0.62	0.28
V	V	6	0.22	0.20	0.55	0.28

An initial analysis of variance revealed that participants recalled significantly more items in free recall than serial recall for both actions, $F(1, 23) = 334.260$, $p < .001$, $\eta_p^2 = .936$, and

objects $F(1, 23) = 134.467, p < .001, \eta_p^2 = .854$. Additionally, a one-factor analysis of variance revealed that participants recalled significantly more objects than actions in both free recall, $F(1, 23) = 71.544, p < .001, \eta_p^2 = .757$, and serial recall, $F(1, 23) = 64.310, p < .001, \eta_p^2 = .737$.

Free Recall

Initially, the data were analysed using a 2x2x2x2 (probe type x encoding mode x recall mode x trial length) repeated measures analysis of variance. This revealed a significant interaction between probe type and trial length $F(1, 23) = 7.760, p = .011, \eta_p^2 = .252$. Thus, the data were split according to probe type for further analysis.

A 2x2x2 (encoding mode x recall mode x trial length) analysis of variance was conducted separately for actions and objects. There was a main effect of trial length in memory for actions $F(1, 23) = 30.789, p < .001, \eta_p^2 = .572$ and memory objects $F(1, 23) = 34.243, p < .001, \eta_p^2 = .598$ but no interactions reached significance. Thus, it was decided to collapse across trial lengths in further analysis. Further, two 2 (encoding) x 2 (recall) analyses of variance were conducted for actions and objects (see table 2.7 for the results).

Serial recall

Initially, the data were analysed using a 2x2x2x2 (Probe x Encoding mode x Recall mode x Trial length) repeated measures analysis of variance which revealed a significant interaction between probe type and encoding mode, $F(1, 23) = 7.866, p = .010, \eta_p^2 = .255$, a significant interaction between probe type, encoding mode and recall mode, $F(1, 23) = 8.113, p = .009, \eta_p^2 = .261$, and a significant interaction between encoding mode and trial length, $F(1, 23) = 5.122, p = .033, \eta_p^2 = .182$. There was also a 4-way interaction between probe type, encoding mode, recall mode and trial length that was close to significant, $F(1, 23) = 4.134, p = .054, \eta_p^2 = .152$. The data were split according to probe type for further analysis to investigate the different effects of actions and objects.

A 2x2x2 (encoding x recall x trial length) analysis of variance revealed a significant main effect of trial length for the action recall data, $F(1, 23) = 48.376$, $p < .001$, $\eta_p^2 = .678$ and for the object data, $F(1, 23) = 45.887$, $p < .001$, $\eta_p^2 = .666$, but trial length did not interact significantly with any other factor. Given that there were no significant interactions with trial length for the objects or the actions, it was decided to collapse across trial lengths in further analysis. A 2x2 (encoding mode x retrieval mode) repeated measures ANOVA was performed separately for each probe (actions, objects) in serial and free recall. The results can be seen in table 2.7 below.

Table 2.7. Effects of encoding and retrieval mode for actions and objects in free and serial recall.

	Actions				Objects			
Free Recall	F	df	p	η^2	F	df	p	η^2
Encoding mode	6.45	23.00	.02	.22	1.53	23.00	.23	.06
Recall mode	0.44	23.00	.52	.02	0.06	23.00	.81	.00
Encoding x Recall	0.01	23.00	.91	.00	1.95	23.00	.18	.08
Serial Recall								
Encoding mode	7.88	23	.01	.26	1.68	23	.21	.07
Recall mode	0.12	23	.72	.01	1.26	23	.27	.05
Encoding x Recall	0.84	23	.36	.04	12.48	23	.00	.35

As can be seen in table 2.7, enactment encoding led to better performance for the actions in free recall (Figure 2.8) and in serial recall (Figure 2.10). No main effects for objects reached significance in free (Figure 2.9) or serial recall but a significant interaction between encoding and recall mode was observed for objects in serial recall (Figure 2.11). Post-hoc comparisons showed that enactment encoding with verbal recall led to better performance compared to enactment at both encoding and recall $F(1, 23) = 11.794$, $p = .002$, $\eta_p^2 = .339$. On the contrary, the difference between verbal encoding with enactment recall and verbal encoding with verbal recall did not reach significance, $F(1, 23) = .796$, $p = .382$, $\eta_p^2 = .033$.

Enactment recall was significantly superior after verbal encoding compared to enactment encoding $F(1, 23) = 12.113, p = .002, \eta_p^2 = .345$. However, verbal recall was not significantly different after enactment or verbal encoding $F(1, 23) = .113, p = .740, \eta_p^2 = .005$.

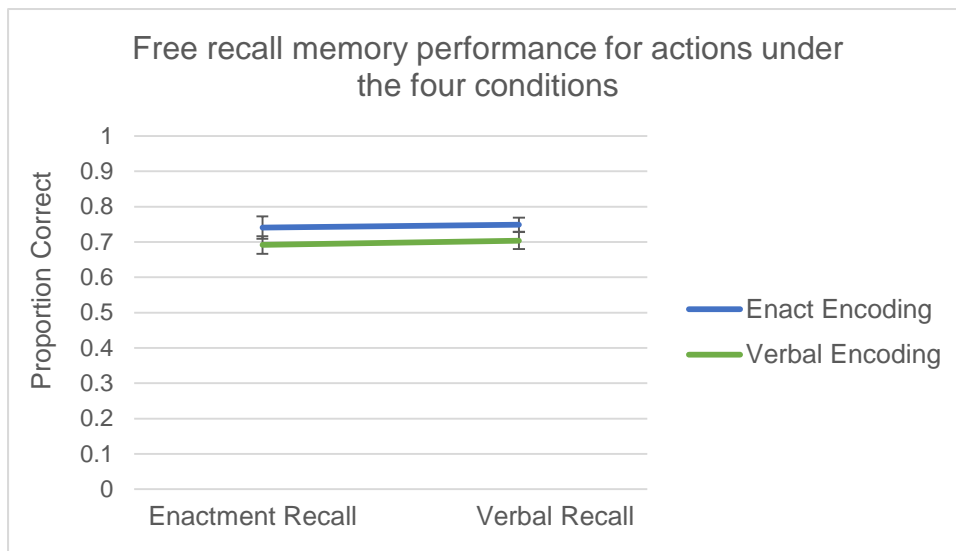


Figure 2.8. Performance for the actions in the four conditions in free recall. Error bars represent the standard error of the mean.

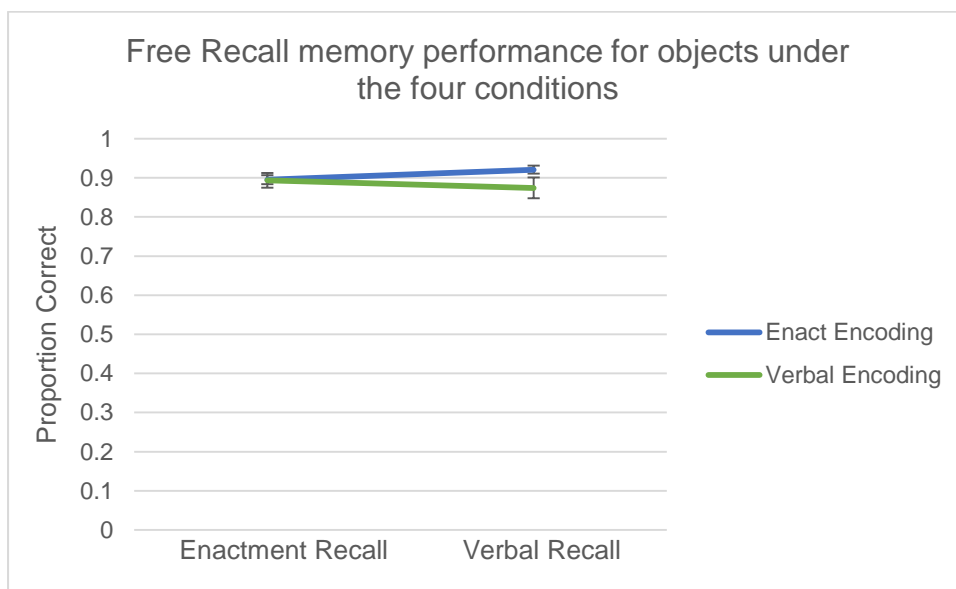


Figure 2.9. Performance for the objects in the four conditions in free recall. Error bars represent the standard error of the mean.

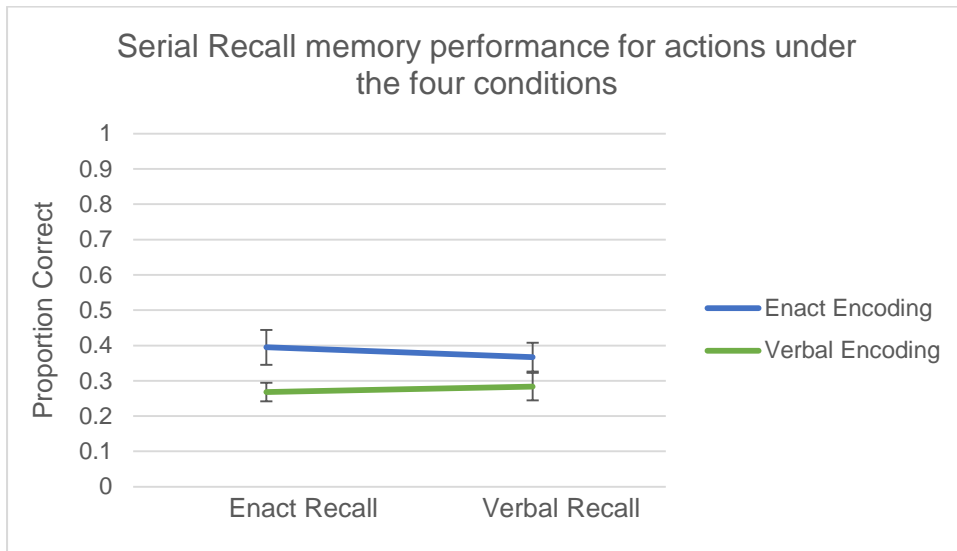


Figure 2.10. Performance for the actions in the four conditions in serial recall. Error bars represent the standard error of the mean.

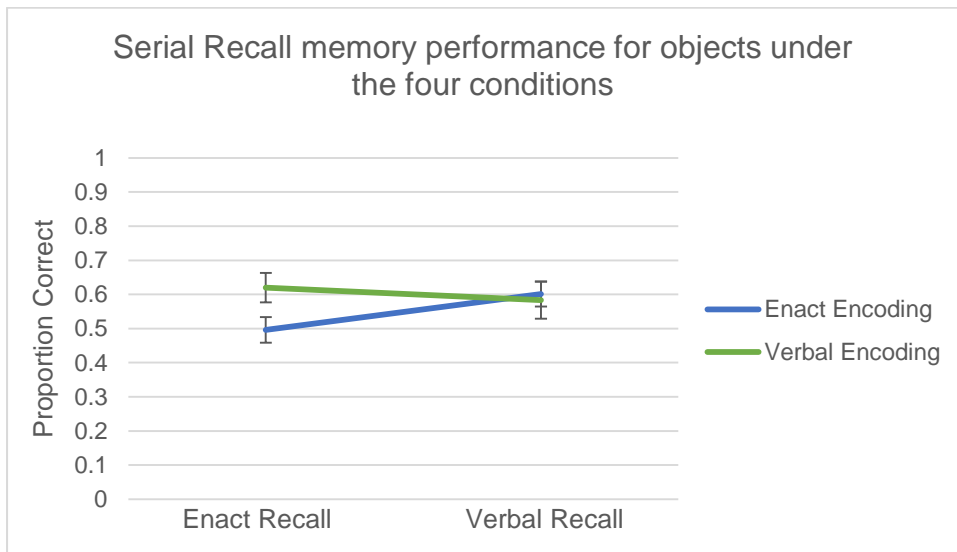


Figure 2.11. Performance for the objects in the four conditions in serial recall. Error bars represent the standard error of the mean.

Short Term Memory

For the Short-Term Memory tasks, the partial credit scores were calculated for each participant. Overall, participants performed significantly better in the STM with digits than the STM with verbs, $F(1, 23) = 105.183$, $p < .001$, $\eta_p^2 = .821$. Since the correlation between the two STM tasks was highly significant, $r(24) = .523$, $p = .009$ it was decided to combine the two for further analysis here.

A correlation analysis between STM and performance in the main 4 conditions in serial recall revealed that STM capacity was highly correlated with verbal encoding but not enactment encoding (table 2.8). As the data show, performance in the encoding enactment conditions was independent of short-term memory capacity.

Table 2.8. Correlations between STM capacity and memory performance in the four conditions for actions and objects.

STM and Probe	Condition			
	EE	EV	VE	VV
STM and actions	-.03	-.07	.39	.47*
STM and objects	-.22	-.06	.09	.02

2.3.3 Discussion

The aim of Experiment 2 was to examine separately memory for actions and objects under enactment and verbal encoding and recall in adults. The main prediction was that adults' action memory would benefit from enactment encoding and retrieval. The results indicate that adults' memory for actions was significantly better after enactment encoding, independently of retrieval mode. This was evident in both free and serial recall performance. This finding is consistent with Engelkamp, Morph and Zimmer (1991) who found a benefit of enactment encoding for action pairs but not objects in adults. In this study, an encoding by

recall interaction for the objects was also observed. This showed that verbal encoding with enactment recall and enactment encoding with verbal recall led to better performance compared to enactment at both stages, but not compared to the verbal encoding and recall condition. Perhaps the dual form of encoding (both verbal and motor) in these conditions enhanced memory for the objects compared to the purely enactment recall. This finding is broadly consistent with Allen and Waterman (2015) who also observed an encoding by recall interaction, whereby enactment encoding with verbal recall led to better performance compared to the other conditions.

In the present study, enactment at recall did not facilitate memory for actions as predicted. Enactment at the recall phase, is thought to enhance performance by the recruitment of action-motor plans laid down during encoding for later execution (Koriat et al., 1990). Perhaps, selectively retrieving one component of the action-object pairing during retrieval, may have prevented participants from forming these plans at encoding. This is because participants had to encode the action-object phrases as one unit, but during retrieval participants had to perform the actions on a different object (zero) or point at the numbers. This change in the object of performance may have indeed disrupted the formation of motor action plans. This possibility will be further addressed in the general discussion of this chapter.

STM scores did not correlate significantly with memory performance for the actions under enactment encoding or enactment recall. This suggests that participants did not solely rely on verbal memory in these conditions but instead used visuospatial or motor memory strategies in all conditions that involved enactment. The only significant correlation was found between STM scores and verbal encoding with verbal recall for the actions which implies that this was the only condition in which participants engaged in verbal rehearsal/memory strategies. Contrary to the objects, memory for actions in this last condition could only rely on verbal memory as there are no cues in the environment to prompt recall. STM scores did not correlate with performance for the objects in any of the conditions. It is therefore suggested that participants used visuospatial strategies to

memorise the objects but compared to children, they did so more effectively. Finally, the finding that only the purely verbal condition correlated with STM scores and the lack of association between all IAFT conditions involving enactment and STM scores, is consistent with the assumptions by Yang, Gathercole and Allen (2014) that enactment performance does not require additional memory resources among adults.

2.4 General Discussion

2.4.1 Summary of findings

Previous research has examined immediate memory for whole action-object phrases after enactment encoding and enactment recall in adults (Allen & Waterman, 2015) and children (Jaroslawska et al., 2016; Waterman et al., 2017). This study aimed to investigate the effects of enactment on memory for actions and objects separately in immediate recall in children (Experiment 1) and adults (Experiment 2). This was an exploratory study since the effects of enactment for actions and objects in encoding and recall have not been examined before directly. First, our findings are consistent with previous studies (Allen & Waterman, 2015; Jaroslawska et al., 2016) showing that enactment at both encoding and recall did not show dual benefits as tested in immediate memory in either age group. That is, enactment at both the encoding and recall stage, was not superior to enactment at one of the two stages (i.e. either enactment encoding or enactment recall). The present study further found that this was the case separately for actions and for objects. This was explicitly evident in adults (Experiment 2) as memory for objects was superior in the conditions that involved enactment in one stage (either encoding or recall) compared to the purely enactment condition (enactment encoding and recall). In turn, this may be taken as evidence supporting the one-component hypothesis (but see general discussion, section 5.3.4).

In the experiments reported in this chapter, enactment at encoding and at retrieval benefited memory for both actions and objects in children and in adults but in a different manner. For children, the findings suggest that enactment encoding led to superior memory

for objects and enactment recall benefited memory for actions. On the contrary, adults showed a benefit of enactment encoding for actions and an encoding by retrieval interaction for the objects. This interaction showed that adults' object memory benefited the most when retrieval and encoding were in different modes (i.e. enact encoding with verbal retrieval and verbal encoding with enactment retrieval) compared to enactment at both stages but not compared to verbal recall in both stages. This may suggest that adults were able to use both verbal and visuospatial resources effectively to aid performance. However, this seemed to be effective only for memory for objects but not actions. Finally, children's performance correlated with STM scores only for the verbal encoding conditions of the IAFT, but for adults only the purely verbal condition was related to STM scores. However, due to the small sample size, the correlation analysis should be treated with caution; it may well be that the current experiment lacked the power to detect any reliable relationships between the IAFT and STM capacity. Nevertheless, overall there is a different pattern of enactment benefits for actions and objects in children and adults, which suggests that enactment effects may be susceptible to developmental changes.

2.4.2 Memory for actions

Children did not seem to benefit from enactment encoding for actions as adults did. The lack of enactment encoding benefits in immediate recall in children has been observed before (e.g. Waterman et al., 2017). As mentioned in the discussion of Experiment 1, this may be due to task difficulty; the low performance rates in children show that they found the task very demanding. Children did, however, benefit from enactment retrieval in serial recall, an effect that also has been found in this age group in the past (Gathercole et al., 2008, Jaroslawska et al., 2016; Waterman et al., 2017). The novel finding in the present study is that this benefit of enactment at immediate retrieval in children is driven by better performance for the action words.

On the contrary, although adults showed a significant effect of enactment encoding in both free and serial recall for actions, enactment at retrieval did not lead to superior

performance compared to verbal recall for adults. This suggests that the disruption of motor plans that may have impaired adult performance in enactment recall as discussed above, did not impair children's performance. This assumption is further discussed below.

2.4.3 Memory for objects

Both age groups showed benefit from enactment for object memory but again these effects manifested differently in children and adults. Children's exhibited an encoding benefit in free recall. This is consistent with Jaroslawska et al. (2016) who also found an enactment encoding benefit in children, although they examined memory for whole action-object phrases. The interaction between encoding and recall mode for object memory in adults is also partially consistent with the findings by Allen and Waterman (2015) who observed a similar pattern, although again they examined memory for whole action-object phrases.

2.4.4 Interpretation of findings and limitations

These differences between enactment benefits in children and adults can be potentially explained by developmental changes in information binding and integration in working memory. In enactment encoding, participants listened to the instructions and had to enact them using the objects. In contrast, during enactment retrieval participants had to either point at the objects or perform the actions on a different object (zero shaped foam object) depending on the probe to be recalled. Adults may have been able to utilise both verbal and motor information maintenance during the enactment encoding phase which in turn led to superior performance. For instance, they may have been able to combine auditory, motor and visuospatial information into a rich representation. Additionally, adults may have been more efficient in binding action and object information than children (Cowan, et al., 2006). Adults may also have used visuospatial information to facilitate memory (for example remembering or imagining *shaking the 8 in the far-left corner, taping the 3 in the bottom right corner*). For instance, previous research has observed that action and features (such as objects) binding is facilitated by enactment in adults (Yang, et al., 2016).

However, this kind of modality integration as well as item binding (action-object pair) during encoding in adults may have disrupted performance in enactment retrieval during which participants had to perform the actions on a completely different object. This is because the action-object phrase had to be dismantled and only one feature had to be retrieved. Presumably, this may have imposed additional central executive demands, and thus impaired enactment recall. As Yang et al. (2016) reported, the disruption of the central executive seems to affect information binding under enactment as well as verbal recall in adults. Additionally, for action memory the enactment recall condition would also mean losing visuospatial information (since participants had to perform the actions on a different object). The encoding by retrieval interaction for object memory in adults supports this hypothesis; participants' memory showed the most benefit when retrieval was in a different mode than was encoding, suggesting that both verbal and motor information were contributing towards memory maintenance. These assumptions are further supported by the lack of correlations between all three conditions involving enactment and STM scores in adults. This suggests that adult participants did not solely depend on verbal maintenance but, rather, they made use of other strategies as well. This is evident by the enactment encoding benefits for actions which suggests the involvement of motor processing.

On the contrary, as children's performance rates show, they found the task very difficult and may have not been able to integrate visuospatial, verbal, and motor information simultaneously, at least not as effectively, as adults. Therefore, in enactment encoding they may have relied on only one encoding method (by paying more attention to either verbal, visuospatial or motor information). In addition, children may not have been as successful in item binding during enactment encoding (action-object pair). As mentioned above, children are not as effective at information binding as adults (Cowan et al., 2006). In turn, if the lack of integration and item binding was what inhibited enactment encoding benefits in children, it may also explain why enactment performance showed benefits in retrieval. In other words, it could be hypothesised that separating the information at retrieval did not lead to additional

costs for children as it did in adults because the information was never well integrated in the first place.

2.4.5 Final Remarks

To summarise, previous literature has established that enactment in WM leads to better memory performance compared to verbal conditions both at encoding and recall in children and adults. The current findings show that splitting the action-object phrases at retrieval seems to impair overall enactment performance. This manipulation was crucial in this experiment in order to study separately memory for actions and objects under enactment. The findings suggest that this manipulation may affect negatively enactment performance and especially enactment at retrieval. Although examining the consequences of the splitting of information (actions and objects) was not the purpose of this study, the findings emerging due to this manipulation may still be informative. For example, the absence of enactment recall effects under this paradigm may suggest that enactment encoding and enactment recall may involve different processes (despite both being mediated by the motor store). This is further supported by the observation that enactment encoding and recall affected differently memory for actions and objects in the two age groups. These assumptions will be further discussed in the general discussion (Chapter 5).

Both age groups benefited from enactment for the actions in serial recall, however, children seem to do so at retrieval while adults' performance was enhanced after enactment encoding. In both cases, this is a surprising finding as enactment is thought to facilitate item information and to inhibit order information (see Chapter 1, section 1.5.1). Therefore, a more prominent enactment effect was expected in free compared to serial recall. The effect of enactment encoding for the objects in free recall fits this assumption but the effects of action memory under enactment in serial recall do not.

Thus, the finding that both adults and children benefit from enactment for actions in serial recall is not entirely consistent with previous findings stating that enactment facilitates item but not order information (Engelkamp & Dehn, 2000). This suggest that the motoric

representations formed during encoding may have a serial nature. This raises the question of whether memory for items and memory for order depend on the nature of the item to be recalled (e.g., action, object) as well as encoding and recall modes (enactment, verbal).

3 Chapter 3. Deconstructing the Enactment effect: Relational processing does benefit from enactment, but this effect is mediated by probe type.

3.1 Introduction

The second chapter reported two experiments looking separately at memory for actions (verbs) and objects (nouns) in four enactment-verbal encoding and recall conditions in children and in adults. The findings suggested a different pattern for action and object memory in free and serial recall. The surprising finding was that a benefit for actions under enactment in serial recall was observed in children and adults. Previous research on enactment in long-term memory using whole action-object phrases has repeatedly reported that enactment facilitates item information but does not benefit- or even hinders- order information (Engelkamp, Seiler & Zimmer, 2004). However, research on working memory and enactment typically examines memory in serial recall (which involves order information) and has reported benefits of enactment both during encoding and recall in children and adults. (Jaroslawska et al., 2016; Waterman et al., 2017). This pattern of enactment effects in serial recall when examined in working memory, is more consistent with the results obtained in the experiments reported in Chapter 2. Therefore, this implies that enactment in short and long-term memory retrieval may involve different processes. This is because enactment in long term recall hinders order memory while it facilitates item information but enactment in WM seems to benefit order information. This is because in the latter case, memory is always examined using a serial recall procedure and the enactment effects persist (e.g. Jaroslawska et al., 2016; Jaroslawska et al., 2018). The effects of enactment for item information in WM have not yet been examined directly. However, the findings in Chapter 2 suggested that enactment encoding enhances item information for actions in adults and for objects in children. Furthermore, the benefit of enactment in serial recall was

evident only for the actions, not the objects in both children (Experiment 1) and adults (Experiment 2).

3.1.1 Item and Order information in enactment

According to the item-order hypothesis (see Chapter 1, section 1.5.1), enactment at encoding is thought to increase long-term memory for the studied items by providing more detailed information about the unique features of these items (Engelkamp & Zimmer, 1995). However, although enactment is thought to enhance item-specific processing, it is believed to hinder order information as studied in delayed recall tasks (Schult, Stulpnagel & Steffens, 2014). For example, Olofsson (1996) found that after enactment, order information for short action-object phrases was impaired compared to verbal presentation. In this experiment, adult participants encoded the information either verbally or through enactment using a between-subjects design. The study material consisted of phrases such as “close the box” and “look at the photograph”. There were six action-object phrases per trial and a total of four trials before the recognition task. An additional manipulation was employed whereby half of the participants in each condition were made aware that the final test will be an order reconstruction task while the other half were simply told they would be asked to recall the items at the end without any further details about the nature of the test. The findings from this study showed that verbal encoding led to greater order reconstruction performance compared to enactment. Furthermore, participants in the verbal encoding condition, significantly benefited from knowing the type of recall, while participants in the enactment encoding condition did not. These results were further replicated in a second experiment that employed a within-subjects design. The findings from Olofsson (1996) provided strong support for the assumption that compared to verbal encoding, enactment does not benefit order information. Furthermore, even when participants in the enactment condition were aware of the subsequent reconstruction test, they still failed to benefit from this knowledge. This suggests that enactment encoding does not allow for successful planning of future verbal order recollection, at least not in delayed recall.

Additional evidence that order memory is impaired after enactment in long-term recall was reported by Engelkamp and Dehn (2000) who examined enactment and the item-order hypothesis in five experiments. Participants encoded the information either by self-enactment (SPT) or by observing the experimenter performing the actions (EPTs) or a combination of both (mixed lists). In these five experiments, Engelkamp and Dehn employed additional manipulations regarding study list length (short-long lists), recall type (free recall, order reconstruction or recognition) and design (within-between subjects). Their findings suggested that, overall, enactment encoding improved item recognition compared to observation, but observation led to significantly better reconstruction performance compared to enactment encoding. This finding was present in the between subjects design but not in the within subject design where order performance was similar for both encoding conditions, suggesting carry-over effects (Experiments 1 & 2). Finally, order information for long lists was very poor for both encoding conditions (EPTs and SPTs). Similar findings regarding poor order recall after enactment encoding were also observed by Schult, Stulpnagel, and Steffens (2014) who examined enactment versus observation encoding and item-order recall (see Chapter 1, section 1.5.1.). Overall, the findings from the long-term enactment literature are quite consistent in indicating that enactment increases item-specific information but does not benefit order information compared to either verbal or observation encoding.

3.1.2 Enactment in WM and Serial information in children and adults

Recent research on enactment in WM paints a different picture as such studies exclusively examine memory in serial recall. Nevertheless, benefits of enactment at encoding and at recall are consistently reported. For instance, Allen and Waterman (2015) examined enactment versus verbal encoding and retrieval in WM in adults and demonstrated clear enactment effects (for further details on this study see Chapter 1, section 1.3.1). This study also examined serial position effects and found that enactment encoding benefits were driven by enactment superiority for the later sequence positions while

enactment recall was superior at each serial position. The typical serial position curves in enactment recall show that, at least within WM, enactment shows the same serial effects as verbal memory. Additionally, Allen and Waterman (2015) also found strong primacy effects under enactment although it has previously been suggested that enactment performance does not show primacy effects of the same strength as verbal encoding (Cohen, 1981). Similarly, Yang, Jia, Zheng, Allen and Ye (2018), examined enactment in forward and backward recall in young adults and also found standard serial position curves in enactment recall. Taken together, these findings suggest that action memory, within a WM paradigm, demonstrates similar serial effects to verbal memory, which may be an additional indication that enactment in WM and LTM involve different mechanisms.

Similar findings to those reported in the adult literature have been observed in WM and enactment studies in children. For example, Jaroslawska et al. (2016), examined enactment at encoding and recall in 8-year-old children under serial recall conditions. In the first experiment, participants encoded instructions in three different conditions; No enactment (auditory encoding), enactment (auditory plus action encoding) and orthographic (auditory plus written encoding). Subsequently, participants recalled the information either verbally or through enactment. The instructions used in this experiment involved two actions (pick up, touch), five objects (ruler, pencil, eraser, folder, box) and three colours (yellow red, blue) creating instruction sentences such as; pick up the blue ruler and put it in the red box". The task followed a span procedure whereby items increased from one to six per trial and the task ended when participants failed to recall correctly any of the three trials at a given span level. Items were scored as correct if they were recalled in the correct order. The results suggested that enactment at encoding led to superior memory performance compared to the other two encoding conditions (orthographic and auditory). Enactment at recall also led to greater performance compared to verbal recall after enactment as well as verbal encoding (however orthographic encoding eliminated enactment at recall benefits).

In the second experiment reported in this paper (Jaroslawska et al., 2016), the orthographic encoding condition was replaced by a verbal repetition condition whereby

participants listened to each instruction sentence and had to verbally repeat it before moving to the next item (shadow condition). The results from this second experiment were consistent with the authors' previous finding showing an enactment advantage at encoding and at recall over verbal or shadow encoding as tested using serial recall. These findings clearly indicate that in immediate recall, enactment supports - or at least it does not hinder - order information. However, it should be noted that in this paper, individual scores for each instruction element (i.e., action, colour, object) are not reported as the authors examined memory for whole sentences. Additionally, in this study the instructions involved only two actions compared to a total of fifteen objects. Therefore, it is not clear whether the enactment advantage in serial recall was mediated by actions, objects or the combination of the two. Nonetheless, the studies that have examined enactment in WM have done so in serial recall and have consistently reported enactment benefits in children and adults (for example Waterman et al., 2017; Yang, Allen & Gathercole, 2014; Yang, Gathercole & Allen, 2016).

3.1.3 The present studies

Therefore, it seems that enactment within a WM paradigm facilitates serial recall (which implies memory for order information). This is at odds with the long-term memory literature which argues that enactment does not provide good serial order information but only benefits item information. This difference between enactment in WM and LTM may in turn suggest that immediate and delayed action recall involve different mechanisms. However, in order to provide further evidence for this argument, it is necessary to examine directly memory for item and order information in working memory under enactment (rather than making assumptions based on free-serial recall conditions performance) which could be then directly comparable to similar long-term memory studies. Furthermore, an additional question is whether the enactment effects for order information are driven by effects that relate to the actions per se, or to the additional information involved in the instructions to be memorised

(e.g., the objects). This is because, although previous studies have not examined this directly, the findings of this current project reported in Chapter 2, suggest that it is the actions that benefited from enactment in serial recall among both adults and children (although this varied as adults benefited from enactment encoding and children from enactment recall). To the contrary, the finding in experiment 1 that enactment encoding in free recall led to superior performance for the objects is in accordance with the item-order hypothesis and the existing long-term memory research. This provides a possible alternative explanation for the differences between enactment in WM and LTM for order memory. It may suggest that the finding that enactment enhances item but not order information in LTM might be driven by better item memory for objects. In turn, this strong item processing effect for objects may obscure a benefit of enactment for order information for the actions. In order to investigate this further item and order memory in enactment needs to be examined separately for actions and objects. Finally, since Experiments 1 and 2 showed different patterns for children and adults, suggesting developmental differences in action processing and enactment benefits, the next two experiments aimed to examine these differences further. Thus, two experiments are reported here, testing a group of children (Experiment 3) and a group of adults (Experiment 4).

3.2 Experiment 3

Previous research on Working Memory and enactment in children has found benefits of enactment encoding using a serial recall procedure for whole action-object phrases (Jaroslawska et al., 2016; Waterman et al., 2017). Experiment 1 reported in Chapter 2, examined separately memory for actions and objects in both free and serial recall in children and found enactment benefits specifically for actions in serial recall and enactment encoding benefits for objects in free recall. Since the main focus of this project is to examine action processing in working memory, a question that emerged was whether enactment benefits for item and order information depends on the type of information to be recalled (i.e. action or

object) in WM. In order to investigate this further, it was decided to manipulate enactment only at the encoding phase in order to test subsequent item and order recall for actions and objects. The recall phase was identical for both encoding conditions in which participants responded by choosing the correct items on a computer screen. Additionally, two WM measures were employed. The STM tasks that were also used in Experiments 1 and 2 and a Visuospatial WM (VSPWM) task. Chapter 2 speculated that enactment performance may draw on visuospatial strategies. Thus, the VSPWM task was employed in order to examine whether enactment performance for actions and objects related to VSP aspects of WM. Based on previous findings (see chapter 2), it was hypothesised that compared to verbal repetition, enactment would lead to superior item-specific memory for the objects while order reconstruction memory would benefit from enactment but this benefit would be specific to actions.

3.2.1 Method

Participants

34 children ($mean_{age} = 8.05$ years, $SD_{months} = 0.63$) took part in a quiet room in the Bristol Cognitive Development Centre (BCDC) lab at the University of Bristol. Participants were randomly selected from the University database. The sessions lasted approximately 50 minutes. Children received stickers and a small toy for their participation while their parents/carers were given £5 towards their travel costs. Full parental informed consent was received prior to the study and verbal consent was obtained from each participant prior to the session. The project was approved by the University of Bristol's Faculty of Science Human Research Ethics Committee.

Design

The study employed a 2x2x2 within-subjects design manipulating encoding mode (enactment or verbal), probe type (action or object) and response mode (item recognition or order reconstruction). The independent variables were probe type, encoding and response

mode. The dependent variable was accuracy and it manifested in two levels; for the order reconstruction trials, an item was scored as correct if that item was correctly identified and in the correct serial position. For the item recognition trials an item was scored as correct if it was part of the given trial independently of position.

Material and procedure

IAT

The study used the same material as in Experiment 1 to maintain consistency. The stimuli were eight foam objects shaped as numbers (1-8) and eight action verbs. These created a total of 64 possible action-object pairs. Using these stimuli, a total of two blocks of action-object phrases were created (one for each condition, counterbalanced across participants). Each block contained 16 trials and each trial consisted of four action-object phrases. This span level of four pairs was chosen as the most appropriate based on our previous work and after a review of the literature. The stimuli were pseudorandomised so that no action verb or number object would appear twice in one trial or in the same exact position in the previous or next trial. Overall, each pair appeared once or twice in each block and two or three times throughout the study. A desktop computer was used for the response phase. The task was created using the Psychopy software (Peirce, 2009). The stimuli were presented auditorily at a rate of 1200ms per action-object phrase with a four second delay between each pair. During that time the screen remained blank. A green star indicated the end of each trial and the beginning of the response phase. The response screen contained either 4 or 8 items (Arial, 18) in a random order but in fixed positions in every response screen for objects (see Figures 3.1 & 3.2) and actions (see Figures 3.3. & 3.4).

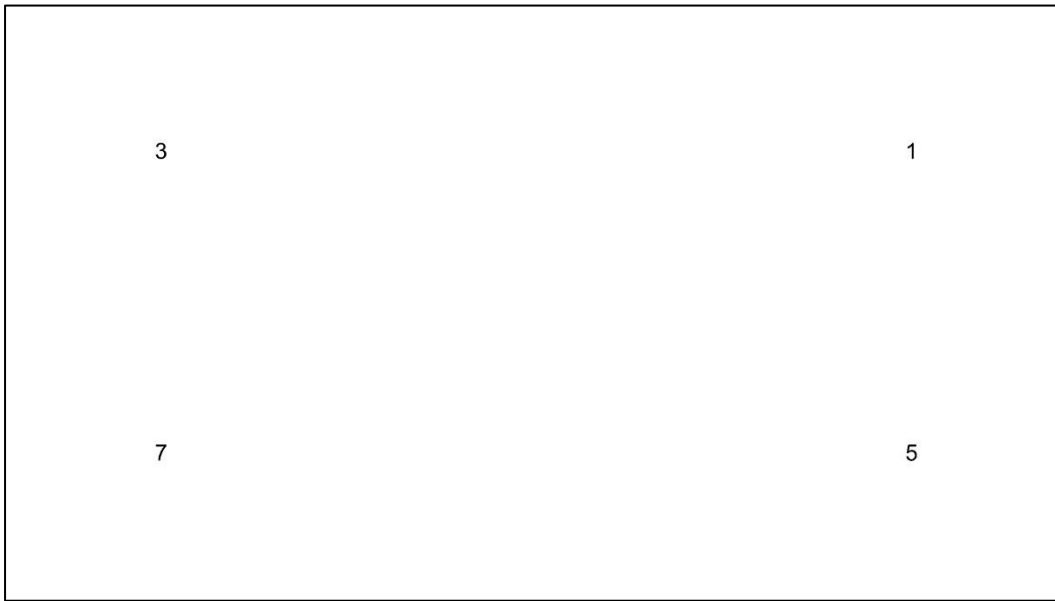


Figure 3.1. Response screen for objects in order reconstruction

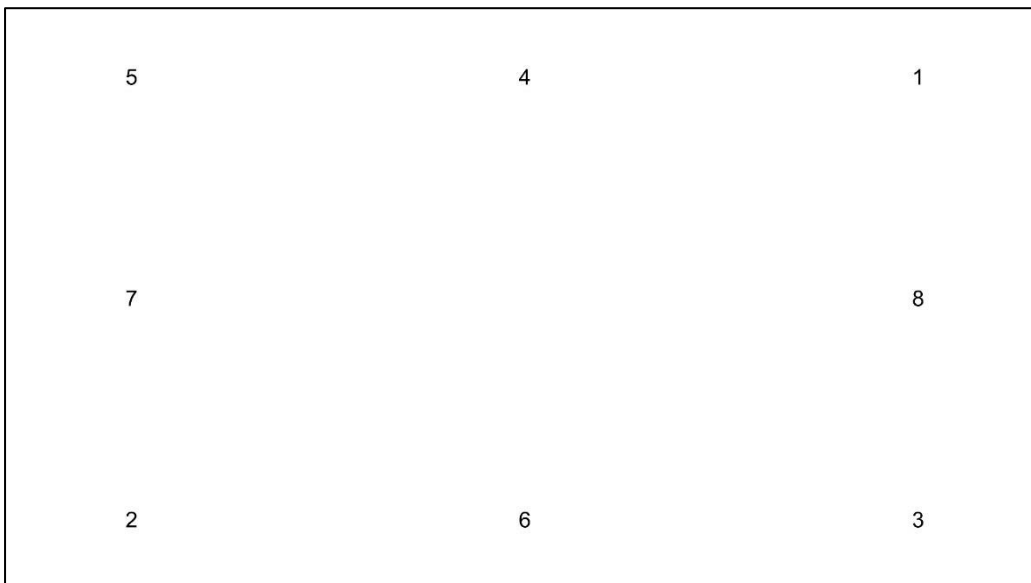


Figure 3.2. Response screen for objects in item recognition

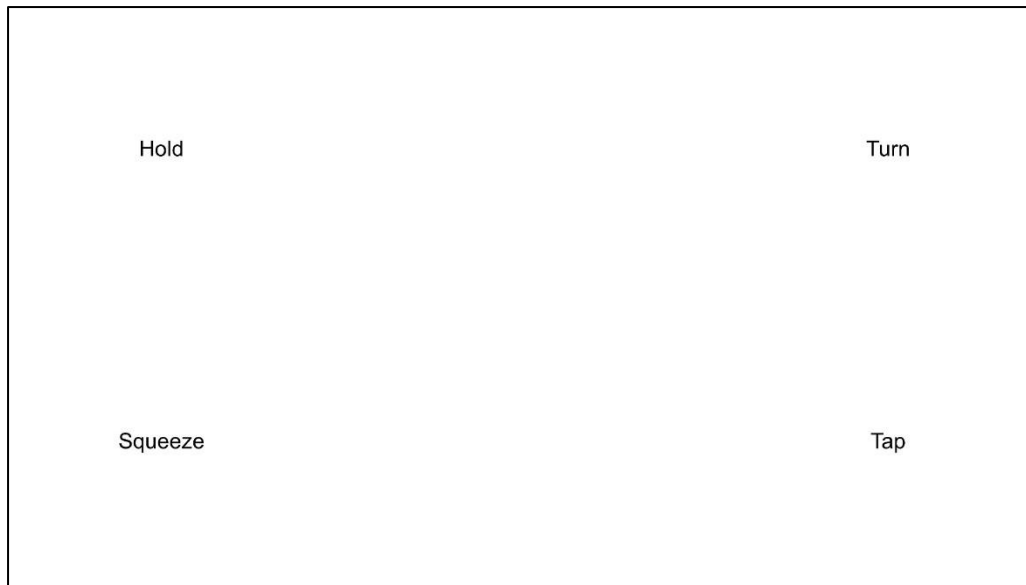


Figure 3.3. Response screen for actions in order reconstruction

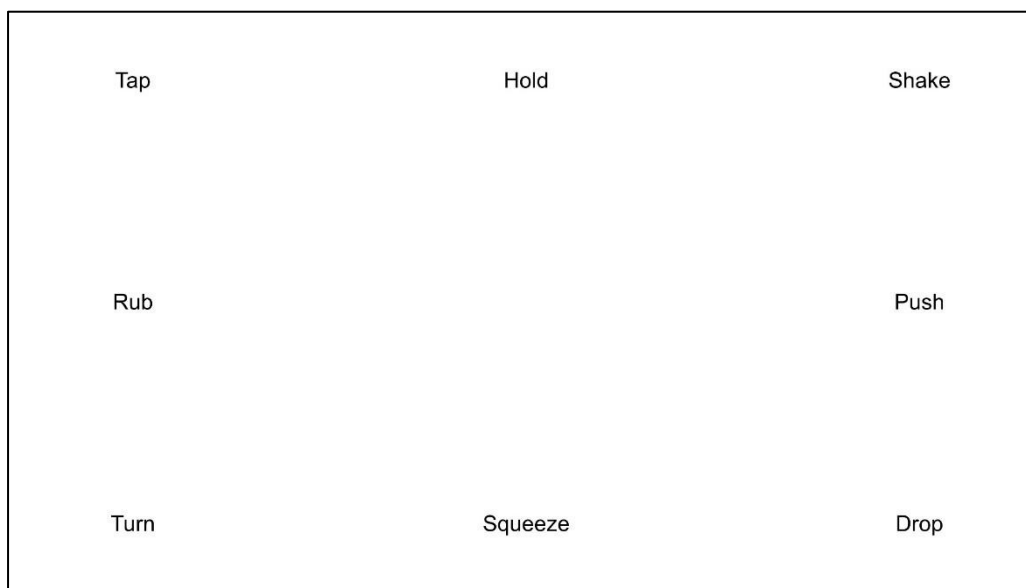


Figure 3.4. Response screen for actions in item recognition

Procedure for the IAFT

IAFT Encoding

Participants listened to four action-objects pairs per trial (e.g. squeeze the three, shake the one, tap the seven, drop the five). There was a four second delay between each action-

object pair during which participants either performed the instruction (enactment encoding) or they verbally repeated it (verbal encoding). At the end of each trial participants saw a green star on the screen indicating the beginning of the response phase.

IAFT Response Phase

Item Recognition trial

For item-specific memory, participants saw a screen displaying all eight numbers (if it was an object trial) (figure 3.2) or all eight verbs (if it was an action trial) (figure 3.4) in a random order. Participants were instructed to recognise the four of these items that were present in the last trial. They were asked to do so by clicking on those items in any order they wished.

Order Reconstruction trials

For order reconstruction memory, participants saw a response screen displaying the four numbers (figure 3.1) or verbs (figure 3.3) presented in the last trial in a random order. They were instructed to click on those four items in the order they were presented. Participants were instructed to press the space bar to continue to the next trial.

Short Term Memory (STM) and Working Memory (WM) tasks.

Participants also completed two STM tasks, one with digits (STMD) and one with verbs (STMV). Both these tasks used the same stimuli as the IAFT. That is, the same action verbs for the STMV and the numbers 1-8 for the STMD. The span for the STM tasks ranged from two to eight items per trial. There were three trials per span level. If a participant completed at least one trial correct in each span level, they automatically moved to the next higher level. The task stopped when the participant recalled incorrectly all trials in a given span level. The STM tasks were created and presented on Microsoft PowerPoint. The items were auditorily presented at a rate of one per second and there was a one second delay between the presentation of each item. During this phase the computer screen remained blank. A

blue circle appeared at the end of each trial to signify the beginning of the response phase. Participants had to verbally recall the items in the correct order and the experimenter recorded their responses. The response phase was self-paced. The experimenter sat on the left-hand side of the table and recorder participants' responses manually using a laptop.

Participants also completed a visuo-spatial Working Memory task (VSPWM) which was created in Psychopy (Peirce, 2009). In this task, participants had to memorise the location of a target (pink sheep) that appeared in different positions on each screen. Each picture also involved two types of distractors namely, same-shape (black sheep) and same-colour (pink elephant) distractors. In total each picture displayed 8 items (1 target and 7 distractors) (see figure 3.5). Participants were instructed to locate the target in every screen, remember its position and then move to the next screen by pressing the space bar when ready. At the end of the trial, participants saw a screen displaying the target in all the possible locations (eight). They were asked to click the same target positions as those that were presented throughout the trial in the correct order (see figure 3.6). The task was self-paced. The span ranged from two to six pictures per trial while participants completed 3 trials at each span level. The task continued if the participant completed at least one correct trial at each given level. The task stopped if no trials were recalled correctly at a given span level.

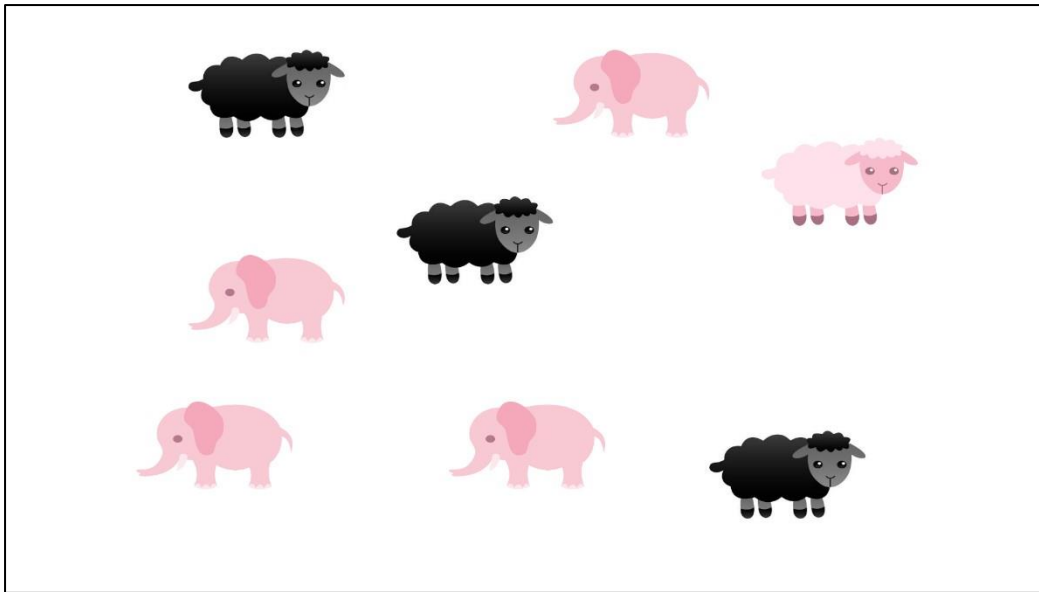


Figure 3.5. Example of one screen of the VSPWM task. Span ranged from 2 to six screens per trial.

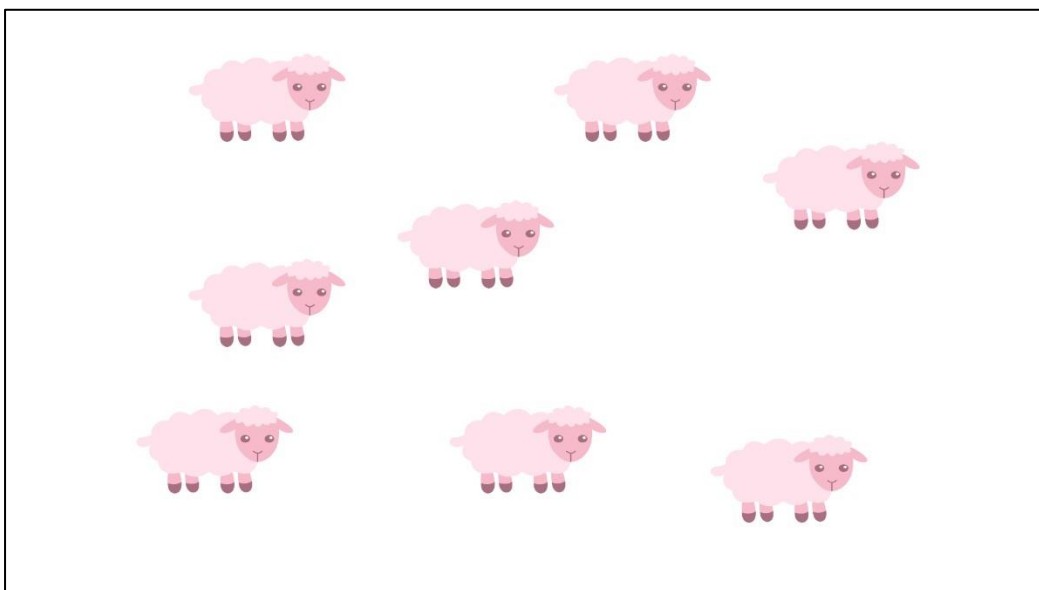


Figure 3.6. The response screen of the VSPWM task. Participants were asked to click on the pink sheep that corresponded to the locations of the pink sheep of that trial in the correct order.

Reading Task

Participants' reading ability and speed were also measured. In total two lists containing the eight verbs of the IAFIT in a different order were created. Participants were given the lists (one at a time) and were asked to read them out loud while the experimenter timed them.

None of the participants had difficulty reading the words accurately. The mean reading speed of the eight words was 5.79 seconds ($SD=1.87$).

Experiment Procedure

For the IAFT, participants completed a total of two separate blocks, one for enactment encoding and one for verbal encoding. Probe type (action vs object) and response mode (item vs order) were manipulated within blocks in sixteen pseudorandomised trials so that not all order or all item trials and not all action or all object trials would occur successively. Other than this manipulation item and order and object and action trials occurred randomly. Therefore each block contained eight item and eight order trials. Of those, four were action and four were object trials. Crucially, participants were not aware of the type of recall prior to the response phase. Thus, they did not know whether at the end of the trial whether they would be asked to recall the action verbs or the numbers, or whether it would be an order or an item trial. Participants also completed a set of four practice trials prior to each block. If at the end of these trials, participants were still not fully familiar with the rules, they continued practicing until they fully understood the task (see figure 3.7 for experiment set-up).

The session always began with the reading task. After this, participants completed one block of the IAFT, followed by one STM task, the WM task, another STM task and finally the other block of IAFT. The presentation order of blocks (A and B), conditions (enactment and verbal) and STM tasks (STMV and STMD) was counterbalanced across participants. Therefore, half of the participants completed the enactment encoding block of the IAFT at the beginning of the session and half of them completed the enactment encoding block of the IAFT at the end of the session. Participants' responses were automatically recorded by the psychopy program.



Figure 3.7. Example of the experiment set-up.

3.2.2 Results

Scoring

The average correct responses were calculated for each trial. For order reconstruction (and order information within item trials) a response was scored as correct if the correct item was recalled in the correct position. For instance, if in a trial the participant was able to correctly reconstruct the order of two out of the four items that would yield a score of .5 for this trial. If the participant was able to reconstruct the order of all items correctly that would yield a score of 1 for this trial. For the item recognition trials a response was scored as correct if the item selected was part of that given trial. Again, the average score of correct responses was calculated for each trial.

Subsequently, the average score of all trials of a given condition (e.g. order reconstruction of actions under enactment) was calculated for each subject. Order reconstruction and item recognition trials were analysed separately.

Descriptive statistics

The descriptive statistics can be seen in table 3.1 below.

Table 3.1. Means and standard deviations of enactment and verbal encoding memory performance for actions and objects in order reconstruction and item recognition.

Condition	Enactment	Verbal
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N= 34	Actions (SD)	Objects (SD)	Actions (SD)	Objects (SD)
Order Reconstruction	0.50 (0.20)	0.58 (0.18)	0.43 (0.16)	0.67 (0.18)
Item Recognition	0.73 (0.10)	0.80 (0.11)	0.69 (0.12)	0.81 (0.12)

Order reconstruction memory

A 2 (encoding) x 2 (probe type) repeated measures ANOVA showed no significant effect of encoding mode $F(1, 33) = 0.155$, $p = .697$, $\eta_p^2 = .005$. There was a significant effect of probe $F(1, 33) = 25.500$, $p < .001$, $\eta_p^2 = .436$ as participants recalled a significantly greater number of objects compared to actions. There was a significant interaction between encoding mode and probe type $F(1, 33) = 9.806$, $p = .004$, $\eta_p^2 = .229$ as a greater number of objects were correctly recalled after verbal encoding and a greater number of actions was recalled after enactment encoding (see figure 3.8). Post-hoc comparisons confirmed that memory for objects was significantly better after verbal compared to enactment encoding, $F(1, 33) = 5.343$, $p = .027$, $\eta_p^2 = .139$. However, the enactment benefit over verbal encoding for actions did not reach significance, $F(1, 33) = 3.118$, $p = .087$, $\eta_p^2 = .086$. Finally, there was a significant difference between action and object memory for verbal encoding $F(1, 33) = 48.682$, $p < .001$, $\eta_p^2 = .596$, reflecting the fact that object memory was superior to action memory in the verbal encoding condition. However, no significant difference was observed between action and object memory after enactment encoding, $F(1, 33) = 2.668$, $p = .112$, $\eta_p^2 = .075$.

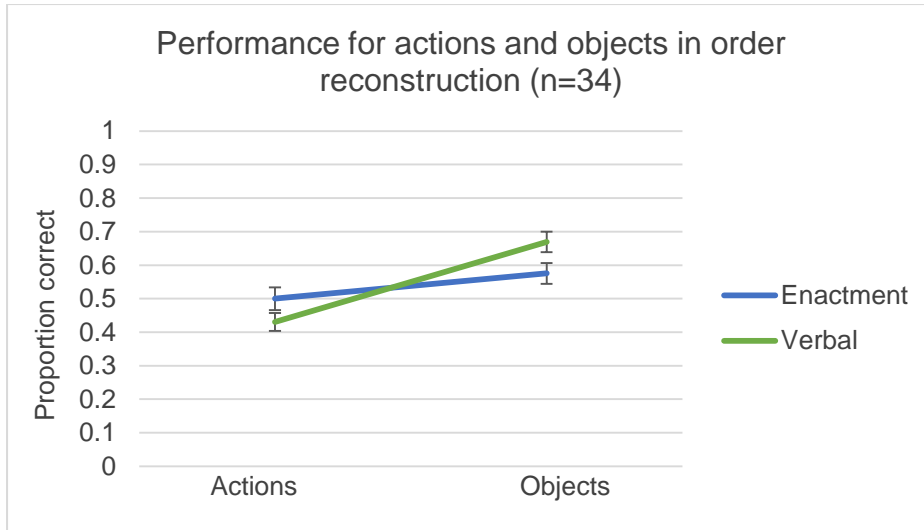


Figure 3.8. Performance for actions and objects after enactment and verbal encoding in order reconstruction. Error bars represent the standard error of the mean.

Item recognition memory

A 2 (encoding) x 2 (probe type) repeated measures ANOVA showed no reliable effect of encoding mode, $F(1, 33) = 0.770$, $p = .387$, $\eta_p^2 = .023$. There was a significant effect of probe $F(1, 33) = 38.283$, $p < .001$, $\eta_p^2 = .537$ as participants recalled a significantly greater number of objects compared to actions. There was no significant interaction between encoding mode and probe type, $F(1, 33) = 1.771$, $p = .192$, $\eta_p^2 = .051$ (see Figure 3.9)

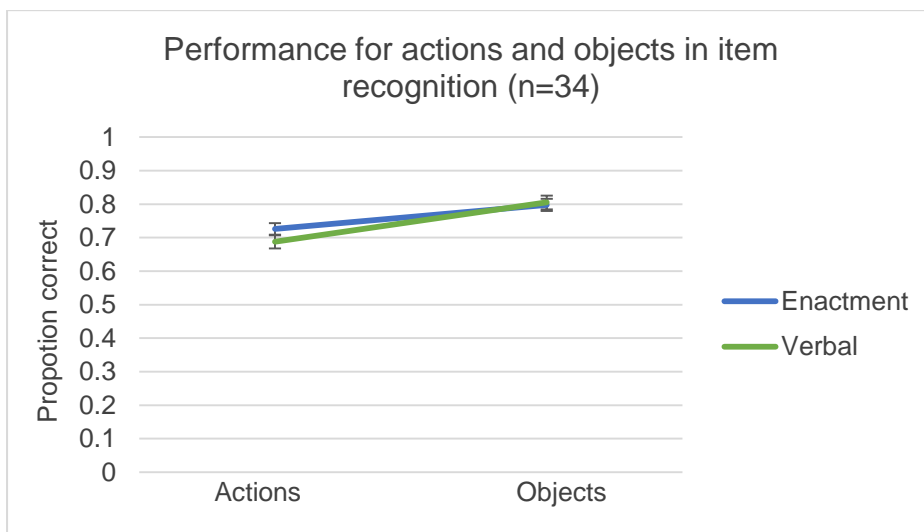


Figure 3.9. Memory performance for actions and objects after enactment and verbal encoding in item recognition. Error bars represent the standard error of the mean.

Item trials – Order reconstruction

This analysis also examined the order reconstruction data within the Item trials. That is, occasions when participants clicked on the items in the correct order although they were not required to do so (as these were item trials and they were instructed to choose the correct items independently of order). These data show a similar pattern to the original order trials (see Figure 3.10).

A 2 (encoding) x 2 (probe type) repeated measures ANOVA of these data showed no reliable effect of encoding mode, $F(1, 33) = 0.691$, $p = .412$, $\eta_p^2 = .020$. There was a significant effect of probe, $F(1, 33) = 47.928$, $p < .001$, $\eta_p^2 = .592$, as participants recalled a significantly greater number of objects compared to actions. There was a significant interaction between encoding mode and probe type, $F(1, 33) = 11.624$, $p = .002$, $\eta_p^2 = .260$, as a greater number of objects was correctly recalled in verbal encoding and a greater number of actions was recalled in enactment encoding thus replicating the findings from the actual order trials. Post-hoc comparisons confirmed that memory for objects was significantly better after verbal compared to enactment encoding, $F(1, 33) = 4.302$, $p = .046$, $\eta_p^2 = .115$. Additionally, the enactment benefit over verbal encoding for actions was significant $F(1, 33) = 4.812$, $p = .035$, $\eta_p^2 = .127$. No other post-hoc comparisons reached significance.

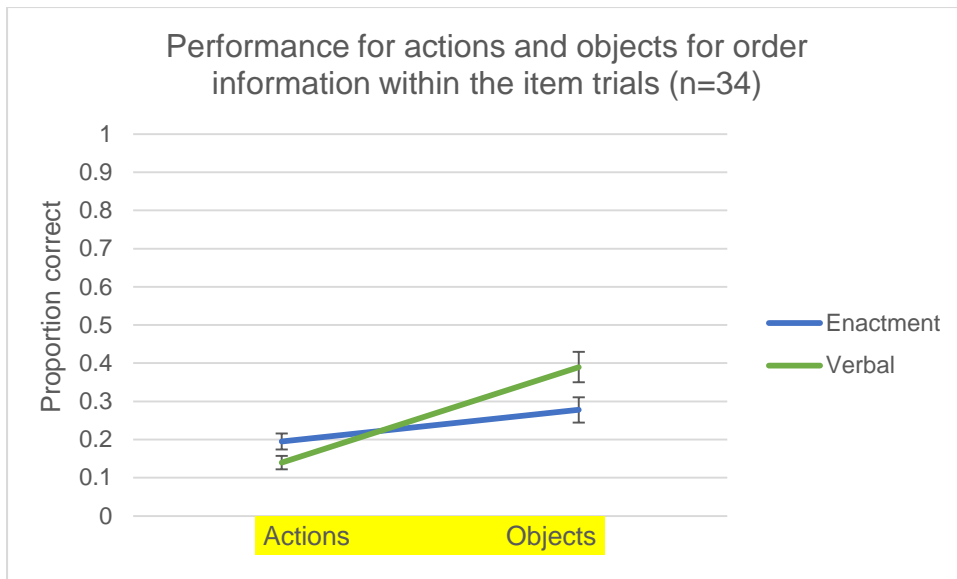


Figure 3.10. Memory performance for actions and objects after enactment and verbal encoding for order reconstruction within item recognition trials. Error bars represent the standard error of the mean.

Correlations

For the STM tasks (STM tasks with numbers and verbs), scores were standardised, and then partial credit scores were calculated for each participant (see Conway et al., 2005). Overall, participants performed significantly better in the STMD than the STMV task, $F(1, 33) = 40.115$, $p < .001$, $\eta_p^2 = .549$. However, since the correlation between the partial credit scores for the two STM tasks was highly significant, $r(34) = .621$, $p < .001$, it was decided to combine the two measures. VSPWM scores were also standardised for further analysis. A subsequent correlational analysis between STM and VSPWM and IAFT performance for actions and objects (see Table 3.2) revealed that STM capacity did not correlate significantly with any of the IAFT conditions. However, there was a strong correlation between VSPWM and performance for the objects in the enactment condition on order trials, suggesting that participants may have used a visuospatial strategy to memorise the objects in this condition.

Table 3.2. Correlations between the IAFT and the additional memory measures (STM and Visuospatial Working Memory).

STM, WM and Probe	Order		Item	
	E	V	E	V
STM and actions	.32	.05	-.22	.23
STM and objects	.11	-.04	.05	.04
VSP WM and actions	-.20	.16	.18	.25
VSP WM and objects	.38*	.10	.28	.05

Note: E= enactment encoding, V=verbal encoding

3.2.3 Discussion

Experiment 3 aimed to investigate enactment and the item-order hypothesis for actions and for objects in children. Consistent with the predictions and previous findings, the evidence suggested that enactment did facilitate, or at least it did not hinder, order reconstruction memory (relational processing). However, this effect was specific to action words. The enactment benefit for actions was indicated in the order reconstruction trials as well as in the order information within the item trials although it reached significance only in the latter. Nevertheless, the clear trend in the order trials, and the fact that the same interaction between encoding and probe type was observed within the item trials, is taken as further evidence that enactment may facilitate order memory for actions. On the contrary, enactment seemed to hinder order memory for the objects, a finding consistent with the item-order hypothesis and LTM enactment research. Overall, objects were significantly better recalled than actions, in both order and item trials, a result that is consistent with the findings reported in Chapter 2 as well as previous literature (e.g., Engelkamp et al., 1990).

Enactment did not benefit item-specific memory in the item recognition trials more than verbal encoding did, and this absence of an enactment benefit was seen for both actions and objects. This finding suggests that differences between WM and LTM with regards to

enactment and order information are not due to an inflated item recognition effect for the objects after enactment, as an enactment effect for objects was not observed here. Therefore, the current findings support the possibility that short- and long-term action benefits may rely on different processes. This point will be further discussed in the general discussion at the end of this chapter. The observation that item memory did not benefit from enactment contradicts previous long-term memory studies that have shown enactment superiority for item-specific information as well as enactment superiority for recognition memory (Engelkamp & Zimmer, 1995).

The lack of reliable enactment main effects is partially consistent with previous studies of enactment in a WM context in children. For example, although Jaroslawska et al. (2016) demonstrated clear enactment encoding benefits, Waterman et al. (2017) found that enactment encoding was detrimental for children's performance. More specifically, Waterman et al. (2017) investigated enactment at encoding using similar material to the present study. Their instructions included 6 actions and 6 objects combined to create novel phrases (e.g. shake the star, spin the sun). On the contrary, Jaroslawska et al.'s material included familiar action-object pairings (e.g. pick up the pen) and additionally their study included only 2 action verbs in the instructions. Waterman et al. (2017) speculated that these differences between theirs and Jaroslawska et al.'s study were responsible for the lack of enactment encoding benefits in their experiment. Indeed, in a follow-up experiment they reduced the number of actions to two and they did find a benefit of enactment encoding. Although the current study differs from Waterman et al. (2017) in many respects (e.g. action-object separation at recall and item-order retrieval), it may still be possible that the lack of enactment main effects may be due to the differences in the experiment material between the current study and Jaroslawska et al. (2016).

Finally, performance in the IAFT did not correlate significantly with STM performance in either of the conditions of the IAFT for either actions or objects. This is partly consistent with the findings from Experiment 1, in which there were no reliable correlations between the enactment encoding-verbal recall condition for actions or objects. However, in Experiment 1

there was a significant correlation between STM performance and memory for actions in the verbal encoding-verbal recall condition, a finding that was not replicated here. A major difference between Experiment 1 and the current study is that the current experiment involved task switching to a greater extent than Experiment 1. In the current experiment, participants at the end of each trial had to either recognise the correct items or reconstruct their order, and in half of the trials this would be for the actions and in the other half for the objects. Crucially, the precise nature of any trial was unpredictable (as trials were pseudorandomised).

Perhaps, the lack of strong correlations between STM and the IAFI suggest that rather than tapping memory capacity per se, the IAFI version employed in this experiment relied on other WM processes (for example, executive functioning). However, if this was the case then performance in the IAFI should correlate with VSPWM capacity, as the latter involves both domain specific and domain general processing, but this was not the case. VSPWM performance correlated significantly only with order memory for the objects in the enactment encoding condition. This shows that VSPWM capacity relates to the extent that participants benefit from enactment encoding when asked to reconstruct the order of the objects.

Overall, the pattern of the data for this sample of children suggests different effects for the actions and the objects in order reconstruction. This is because, in order reconstruction, object memory benefited from verbal encoding and action memory benefited from enactment encoding. However, the type of encoding condition did not seem to affect item recognition memory for either actions or objects. In Experiment 1, the enactment effects for actions in children were observed when enactment was manipulated during the recall phase but not at encoding. Thus, the absence of main enactment effects in this study is consistent with the results from Experiment 1 in that enactment at encoding did not facilitate performance in children in the current paradigm.

3.3 Experiment 4

Experiment 4 aimed to test the same assumptions as Experiment 3, but in an adult population. The purpose of this experiment was to test whether enactment encoding in WM benefits action memory for item or order information (or both) in adults. Based on the long-term memory literature, enactment should benefit item but not order information. However, if action representation in WM involves different processes than action representation in LTM, enactment should also benefit order memory (as previously implied in enactment WM studies that used a serial recall scoring procedure). Experiment 2 (reported in Chapter 2) suggested that participants benefited from enactment encoding for actions in both free and serial recall conditions. Additionally, in Experiment 2 an interaction between encoding and recall suggested that objects' serial recall was greater after enactment encoding with verbal recall and after verbal encoding with enactment recall compared to enactment at both stages. Thus, based on the findings from Experiment 2, it was expected that enactment encoding benefits in order reconstruction would be evident for both actions and objects. As with Experiment 3, a benefit of enactment encoding for the item trials was also expected for the actions, given that in Experiment 2, adults benefited from enactment encoding for actions but not objects in free recall.

This study was identical to Experiment 3 with the difference that all tasks were adapted for difficulty (as explained below) and that the STM tasks were replaced by a Verbal WM task. As mentioned above, the lack of reliable correlation between STM measures and the main task in Experiment 3 raised the possibility that the IAFT used in that experiment may involve complex manipulation of information, rather than simply passive storage. It was therefore deemed appropriate to employ a task that might capture these processes. Thus, a Verbal WM task was developed to replace the STM tasks in this study and to accompany the VSP WM task.

3.3.1 Method

Participants

In total, 41 University Undergraduate students ($Mean_{age}=19.96$ years, $SD_{months}= 1.07$) provided informed consent to participate in the study as part of their course requirements.

The sessions took place in a quiet lab room at the University campus and lasted approximately 50 minutes. The project was approved by the University of Bristol's Faculty of Science Human Research Ethics Committee.

Design

The experiment design was identical to Experiment 3. Therefore, a 2x2x2 within-subjects design was employed, manipulating encoding mode (enactment vs verbal), probe type (action vs object) and response mode (item vs order) as the independent variables. The dependent variable was accuracy and it manifested in two levels; the dependent variable was accuracy and it manifested in two levels; for the order reconstruction trials, an item was scored as correct if that item was correctly identified and in the correct serial position. For the item recognition trials an item was scored as correct if it was part of the given trial independently of position.

Material

IAFT

The materials used in this experiment were identical to Experiment 3 with the following modifications to increase task difficulty. The task involved a total of 10 objects (numbers 0-9) and 10 action verbs while each trial consisted of 5 action-object phrases. This span level was chosen as the most optimal based on pilot work as well as previous findings (see

Experiment 1). The task was created using Psychopy software (Peirce, 2009). As with Experiment 3, two blocks were created, each containing 16 trials.

Verbal WM

In this experiment, the two STM tasks (STMD and STMV) employed in Experiment 3 were replaced by a Verbal Working Memory (VWM) task. The VWM task was created and presented using Microsoft PowerPoint. In this task, a number of targets (dogs) and distractors (cats) was presented on each screen. Participants had to count how many targets they saw in every picture (screen) and remember that number for later recall. The number of pictures per trial ranged from three to eight. Each picture contained a total of 8 items but the number of targets and distractors per picture varied in a pseudorandomised manner (see figure 3.11). This was done to ensure that the same to-be-remembered number of targets would not appear twice in a trial or in the same position in the previous or next trial.

Participants were instructed to count the number of targets in each picture and indicate the sum out loud. They then moved on to the next picture where they followed the same procedure. At the end of each trial, participants had to recall each of the sums of targets for each picture they saw in the correct order. Each span length consisted of three trials. The task ended when participants recalled incorrectly all of the trials at a given span level. The material used to create this task were chosen on the basis that the same task may be used for future experiments with children to maintain consistency across experiments. Thus, the materials were child-friendly for this reason.

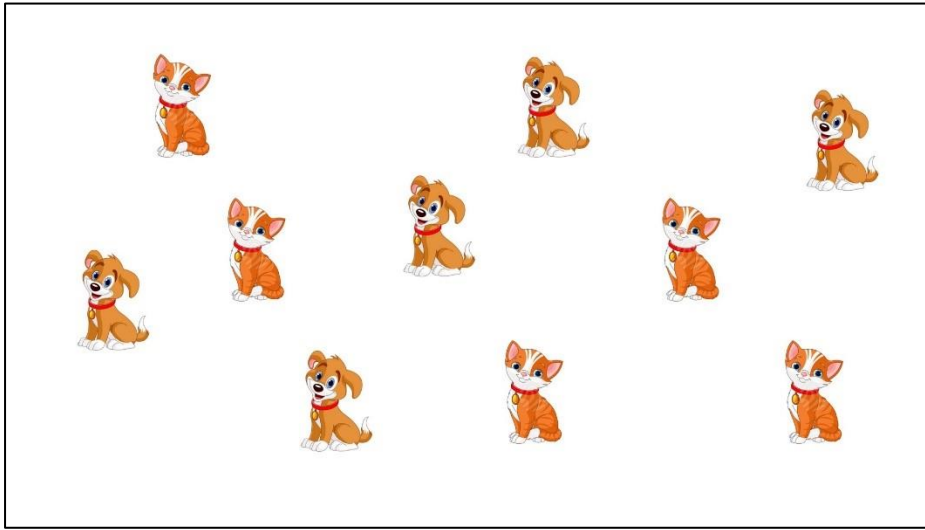


Figure 3.11. Example of one screen in the Verbal WM task.

VSPWM

The VSPWM task was identical to Experiment 3 but the span ranged from three to eight screens to remember in order to adapt task difficulty.

Procedure

The procedure was identical to Experiment 3 but the presentation order differed in the following manner. Participants started by completing one block of the IAFT, then a WM task, then the other IAFT task and finally the other WM task. The order of IAFT condition (enactment and verbal), block (A and B) and the type of WM task (VWM and VSPWM) were counterbalanced across participants.

3.3.2 Results

Scoring

The scoring procedure was identical to Experiment 3 (see section 3.2.2). Order reconstruction and item recognition trials were analysed separately.

Descriptive Statistics

The descriptive statistics can be seen in table 3.3 below.

Table 3.3. Means and standard deviations of enactment and verbal encoding memory performance for actions and objects in order reconstruction and item recognition.

Condition	Enactment		Verbal	
N= 41	Actions (SD)	Objects (SD)	Actions (SD)	Objects (SD)
Order Reconstruction	0.59 (0.18)	0.72 (0.18)	0.53 (0.19)	0.77 (0.16)
Item Recognition	0.82 (0.10)	0.92 (0.08)	0.76 (0.10)	0.92 (0.11)

Order reconstruction trials

A 2 (encoding) x 2 (probe) repeated measures ANOVA was performed in order to explore the effects of enactment vs. verbal encoding on action and object memory in order reconstruction. There was a significant effect of probe type $F(1, 40) = 50.976, p < .001, \eta_p^2 = .560$, with participants recalling significantly more objects than actions. The effect of encoding mode was not significant, $F(1, 40) = 0.009, p = .925, \eta_p^2 < .001$, showing that enactment did not lead to better order reconstruction memory. However, there was a significant interaction between encoding mode and probe type, $F(1, 40) = 7.396, p = .010, \eta_p^2 = .156$. As figure 3.12 indicates, actions were more likely to be recalled in the correct order after enactment rather than verbal encoding while objects were more likely to be recalled correctly after verbal encoding. Post-hoc comparisons revealed that the benefit for action memory under enactment compared to verbal repetition did not reach significance, F

(1, 40) = 3.014, $p = .090$, $\eta_p^2 = .070$, and neither did the benefit of verbal over enactment encoding for the objects, $F(1, 40) = 2.577$, $p = .116$, $\eta_p^2 = .061$. Further analysis showed that there was a significant memory advantage for the objects over the actions in both the enactment condition, $F(1, 40) = 16.265$, $p < .001$, $\eta_p^2 = .289$, and the verbal condition, $F(1, 40) = 51.129$, $p < .001$, $\eta_p^2 = .561$. Therefore, the interaction observed reflects the fact that the difference between object and action order memory was larger in the verbal encoding than in the enactment encoding condition.

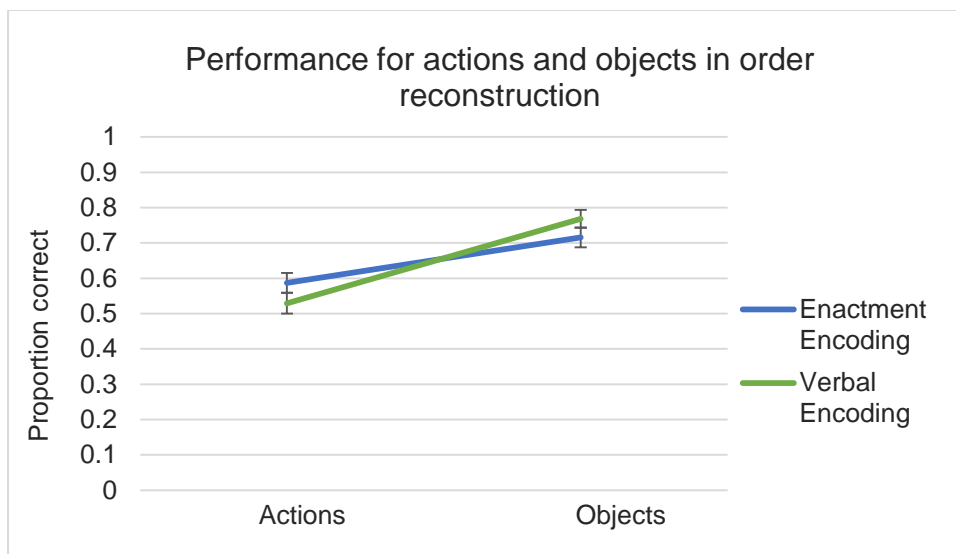


Figure 3.12. Memory performance for actions and objects after enactment and verbal encoding in order reconstruction.

Item Recognition trials

A 2 (encoding) x 2 (probe) repeated measures ANOVA revealed a significant effect of probe type, $F(1, 40) = 140.363$, $p < .001$, $\eta_p^2 = .778$. The effect of encoding mode was close to significant, $F(1, 40) = 3.361$, $p = .074$, $\eta_p^2 = .078$. The interaction between encoding mode and probe type was significant, $F(1, 40) = 7.955$, $p = .007$, $\eta_p^2 = .166$. Figure 3.13 suggests that more actions were recalled correctly under enactment compared to verbal encoding. Post-hoc comparisons revealed that compared to verbal encoding, enactment encoding led to significantly better item memory for actions. $F(1, 40) = 8.382$, $p = .006$, $\eta_p^2 = .173$.

However, there was no significant difference between enactment or verbal encoding for the objects, $F(1, 40) = .221, p = .641, \eta_p^2 = .005$. Additionally, while objects were more likely to be recalled than actions under both enactment encoding, $F(1, 40) = 30.978, p < .001, \eta_p^2 = .436$, and verbal encoding, $F(1, 40) = 126.416, p < .001, \eta_p^2 = .760$, this difference was clearly more marked under verbal encoding.

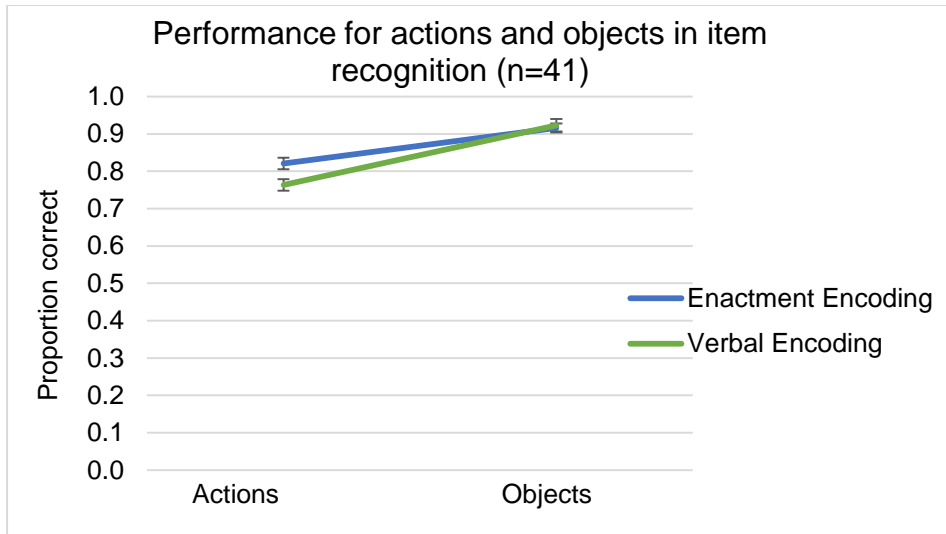


Figure 3.13. Memory performance for actions and objects after enactment and verbal encoding in item recognition. The error bars represent the standard error of the mean.

Item trials – Order reconstruction

This analysis also examined the order reconstruction data within the Item trials. That is, occasions when participants clicked on the items in the correct order although they were not required to do so (as these were item trials and they were instructed to choose the correct items independently of order). A 2 (encoding) x 2 (probe type) repeated measures ANOVA of these data showed no reliable effect of encoding mode, $F(1, 40) = 1.217, p = .277, \eta_p^2 = .030$ nor a significant interaction $F(1, 40) = 2.258, p = .141, \eta_p^2 = .053$. The effect of probe type was significant as objects were recalled more than actions $F(1, 40) = 67.075, p < .001, \eta_p^2 = .626$.

Correlations

Partial credit scores were calculated for each participant for the Verbal and the Visuospatial WM tasks. A correlation analysis between the two WM measures and each condition of the IAFT, showed that memory for actions did not correlate with either WM measures in order reconstruction (see table 3.4). To the contrary, memory for actions in the item trials correlated with both WM measures but only for the verbal encoding condition. Thus overall, memory for actions after enactment encoding did not correlate with any WM measures in either order reconstruction or item recognition. Memory for objects correlated with VSPWM in enactment encoding in order reconstruction. Additionally, memory for objects correlated with Verbal WM in item recognition after both enactment and verbal encoding.

Table 3.4. Correlations between the main experiment conditions and the additional working memory measures (Verbal and Visuospatial Working Memory).

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.09	.04	.04	.39*
VWM and objects	.00	.21	.36*	.43**
VSP WM and actions	.29	.19	.22	.42**
VSP WM and objects	.45**	.22	.04	.26

E= Enactment Encoding, V= Verbal encoding

3.3.3 Discussion

The aim of Experiment 4 was to examine how enactment at encoding affects memory for actions and objects in item recognition and in order reconstruction in adults. It was expected that compared to verbal encoding, enactment will benefit memory for actions in both order reconstruction and item recognition. Based on the findings from Experiment 2 an enactment advantage was expected for objects in order reconstruction. The results showed that memory for actions, but not objects, was better after enactment compared to verbal encoding in both order reconstruction and item recognition. However, the difference in action performance after enactment versus verbal encoding reached significance only in the item trials. Nevertheless, the interaction observed in the order trials between encoding and probe

type echoes the findings from Experiment 3 where the same interaction was observed for the order trials as well as the order information within the item trials. Taken together, the findings show evidence that enactment encoding enhanced order reconstruction performance for actions, which is a novel finding. Additionally, Experiment 4 showed that enactment encoding also led to greater item recognition than verbal encoding, specifically for actions but not objects. These findings are in agreement with Experiment 2, where a benefit of enactment for actions was observed in both serial and free recall in adults. Thus overall, Experiment 4 shows that enactment selectively enhances memory for actions, which implies the involvement of motor processes. The absence of significant main enactment effects is consistent with Experiment 3 but not with previous research on enactment in WM in adults (see Allen & Waterman, 2015; Yang et al., 2016). As mentioned in the discussion of Experiment 3, above, this absence of main effects may be due to methodological issues. Since Experiments 3 and 4 used the same methodology and displayed very similar results, the methodological issues for both studies are addressed in the general discussion of this chapter.

In terms of the WM measures, the overall picture suggests that participants may have recruited a variety of strategies or resources to aid performance. The reason this study employed two WM measures, instead of the previously used STM tasks, was to capture domain general processes, for instance the involvement of central executive. However, if there was such involvement, it would be expected that performance in the IAFT would correlate with both WM measures but that was not the case. Instead, verbal and visuospatial WM independently predicted performance in the different IAFT conditions. Memory for actions correlated meaningfully with WM measures only in the verbal encoding condition in the item recognition trials. Therefore, the only consistent finding with regards to WM in this experiment was the correlations between verbal WM and performance for actions and objects in verbal encoding for item recognition. Performance for the objects in item recognition after verbal encoding also correlated significantly with VSPWM. This is not surprising as previous research on enactment has also suggested that in purely verbal

conditions, participants may still make use of visuospatial strategies to memorise material when those are directly available in the environment (Yang et al., 2018). It should be noted that although action memory was superior after enactment than it was after verbal encoding, memory for actions under enactment did not correlate meaningfully with neither Verbal nor VSPWM. Further this was the case for both order reconstruction and item recognition. This suggests that performance for actions in the enactment conditions may rely on different resources (see Jaroslawska et al., 2018; Yang et al., 2016).

3.4 General Discussion

3.4.1 Summary of findings

The aim of the two experiments reported in this chapter was to examine item and order memory for action and objects after enactment and verbal encoding. It was hypothesised that enactment would benefit order information specifically for actions. It was also hypothesised that enactment would facilitate item recognition for actions and objects in children, and order reconstruction for objects in adults based on the previous studies (Chapter 2) and the literature (e.g. Engelkamp & Zimmer, 1995). The main finding, observed in both experiments, was the interaction between encoding and probe type in order reconstruction. This interaction suggests that compared to verbal encoding, enactment led to better order memory for actions, yet objects were more likely to be recalled correctly in order after verbal encoding compared to enactment. Additionally, the same interaction was observed for item recognition memory but only in adults (Experiment 4). These findings show that enactment encoding in WM may support, or at least does not hinder, memory for order information.

This notion is consistent with previous studies that examined enactment in WM using serial recall in adults and children (Jaroslawska et al., 2016, Waterman et al., 2017; Yang, Gathercole & Allen, 2014; Yang, Allen & Gathercole., 2016), as well as studies that examined serial position effects in enactment (Allen & Waterman., 2015; Yang et al., 2018).

The novel finding from Experiments 3 and 4 however, is that the order reconstruction benefit after enactment encoding is specific to the action elements, at least within the current experimental paradigm. Additionally, evidence for this effect appeared in both children and adults. These findings provide support for the assumption that enactment in WM may involve different mechanisms compared to enactment in LTM as order information was partially supported after enactment in WM. Furthermore, given that an enactment encoding advantage was observed specifically for actions, it is suggested that enactment benefits rely on motor processing.

3.4.2 The one component hypothesis

A possible candidate framework that could accommodate these assumptions is the *one component vs two-component hypothesis*, as described in Jaroslawska et al. (2016). The study by Jaroslawska et al. (2016), described in the introduction (section 3.1.2), aimed to examine whether enactment at encoding and enactment at recall involve the same mechanisms. According to the motor store hypothesis, enactment at both encoding and recall should not lead to additive benefits of enactment since there is only one mechanism involved (i.e. the motor store). On the contrary, the two-component hypothesis would predict that enactment at both encoding and recall should be superior to enactment at one of the stages (enactment at either encoding or recall). This is because, according to the two-component hypothesis, enactment at recall performance relies on the motor store (representations for future action are generated during encoding) but enactment encoding benefits rely on episodic memory. The findings from Jaroslawska et al. (2016) as well as Allen and Waterman (2015) and Waterman et al. (2017) who all examined enactment in WM are consistent with the one-component hypothesis as no additive enactment effects were observed.

However, as Jaroslawska et al. (2016) mention, research on enactment and LTM is more consistent with the two-component hypothesis as enactment memory benefits have been observed beyond WM, in long-term retrieval. Therefore, it may be the case that enactment in

WM relies on the motor store (one-component hypothesis) but enactment in LTM draws upon both motor store resources as well as episodic memory (two component hypothesis). This would explain why enactment at WM exhibits different effects to enactment in LTM with regards to order information. The present experiments (3 and 4) partially support this assumption. Although reliable main effects of enactment were not observed, it was shown that enactment selectively boosted order memory for the actions suggesting the involvement of motor mechanisms. Finally, the lack of reliable correlations between STM and WM measures and action memory in enactment in both samples supports further the motor store hypothesis. This is because the lack of relationship between enactment performance for the actions and WM in both age groups suggests the involvement of processes not captured by the WM tasks.

3.4.3 Interpretation of findings and limitations

Item recognition memory for the actions also benefited from enactment but only in the adult sample. Perhaps, this reflects the fact that children found the task more challenging and the mismatch between encoding and recall presentation in the enactment condition impaired their performance to a greater extent. Furthermore, the complexity of task switching (remembering actions or objects in item recognition or order reconstruction) may have been more challenging for the children. Additional evidence that children found the task switching (i.e. item vs order recall) more challenging can be inferred by the order performance within the item trials. The order data from the item trials mirror the pattern seen in the actual order trials, suggesting that children still attempted to recall the items in the correct order although they were not instructed to. Therefore, the lack of enactment benefit for actions in the item trials in children may be due to the complexity of the task and may reflect their inability to switch between response modes as effectively as adults.

Overall, the absence of enactment encoding main effects is not consistent with previous research (e.g. Allen & Waterman., 2015; Jaroslawska et al., 2016). Given that the enactment effect is well established in the literature, at least for memory for whole action-object

phrases, it appears that the present lack of main effects is due to the methodology employed in the current paradigm. In particular, there are a number of fundamental differences in the experiment design of this study and the classic enactment paradigms in the literature. The most obvious difference can be seen in the material chosen to examine enactment. Previous studies (e.g. Jaroslawska et al., 2016; Yang, Gathercole & Allen, 2014), have predominantly constructed meaningful and familiar phrases and have used everyday objects that participants are daily exposed to. For instance, an example of instructions would be “*put the blue ruler in the green box, **then** put the red pencil in the black envelope*”. These types of instructions create a rich representation, drawing on LTM associations (Waterman et al., 2017) and reinforces a sense of continuity and goal directed behaviour. In other words, they may facilitate planning and order information in a visuospatial manner (given that participants have continuous access to the visual and physical configuration of the material in the environment throughout the study). Additionally, the study by Jaroslawska et al. (2016) only used two action words to feature in the instruction sequences thus posing less demands on WM. When Waterman et al. (2017) reduced the action verbs from 6 to 2, they also observed enactment encoding benefits. Therefore, the enactment encoding benefits observed before in WM may be heavily reliant on the task used (Waterman et al. 2017) and may be the result of familiarity and long-term associations.

On the contrary, the current study created a set of novel stimuli (e.g. push the 5, drop the 1) to deliberately minimise previous associations with the material, semantic representations or LTM knowledge as well as action-object bindings. Equally, another major difference between the existing enactment literature and the current study is that during the recall phase of the current studies participants had to retrieve either the actions or the objects presented, rather than the action-object pairs. These manipulations were crucial in order to examine the pure effects of physical performance on motor action and on object memory separately and strictly within the Working Memory context. Indeed, the current findings suggest that it is the actions only that benefit from physical enactment, although more consistent and robust evidence is needed to confirm this hypothesis. Overall, the lack of

main enactment effects perhaps suggests that the enactment superiority, which is well established in the literature, is the product of a rich representation in which the context, semantic associations from LTM, and continuity or goal directed behaviour all play a crucial role.

Additional methodological issues that may have impaired enactment performance compared to previous studies include the experimental set up and more specifically the discrepancy between encoding and recall modes. In the studies reported in this chapter, enactment at encoding was carried out in a three-dimensional space using real objects. In the recall phase however, participants had to respond to stimuli on the screen. Perhaps, this additional cognitive process of translating motor movements performed in the real world to written words projected on a screen might have weighted the task with additional cognitive demands. This change in representation may have particularly impaired performance in the enactment encoding condition. On the contrary, during verbal encoding, participants heard and verbally repeated the instructions in the form of sentences which they then saw in written form on the response screen. Therefore, it is assumed that the leap between auditory and verbal presentation to orthographic recall was less demanding compared to the enactment encoding condition as it did not require a change of representation. Additionally, as mentioned above, the IAFT was especially demanding in Experiments 3 and 4 as in addition to distinguishing and switching between action vs object recall, participants also had to switch between item recognition and order reconstruction. As mentioned in the methods section, participants had to continuously switch modes between trials as the probe type (action or object) and recall type (item or order) were pseudorandomised between trials and within blocks. Thus, it may be the case that in the current task, the benefits of enactment were masked by the task's demands.

Of course, there is also the possibility that the similarity in performance after enactment and verbal encoding may be due to carry over effects as the studies reported here employed a within-subjects design. Indeed, previous research (mainly in LTM), has consistently found that enactment benefits decrease when enactment is manipulated within-subjects (e.g.

Engelkamp & Dehn, 2000). However, it is important to also note that enactment studies in WM have predominantly used within-subjects designs and have still reported strong enactment effects. Therefore, this explanation should be treated with caution. Finally, it should be noted that the current experiments included a limited number of trials per condition (four trials) per participant. Thus, the present findings should be interpreted with caution due to the lack of power to, perhaps, detect more reliable effects.

3.4.4 Enactment and WM within the current paradigm

In terms of WM associations, enactment performance for object memory in order reconstruction correlated reliably with VSPWM but not Verbal WM, in both age groups. This perhaps suggests that both age groups attempted to encode object locations under enactment encoding. As different tests were used in the two age groups to test verbal memory (STM in children and WM in adults) perhaps it is not possible to make any direct comparisons. Nevertheless, it appears that adults may have relied on phonological aspects of WM in order to memorise the material, as the correlation between verbal WM and the item trials show, yet this may have not been an effective strategy for the order trials. In children, STM scores did not correlate significantly with IAFT performance. It has previously been suggested that the absence of a relationship between the phonological loop and task performance may be due to an overly demanding task that leads to the abandonment of verbal rehearsal (Yang et al., 2016). Perhaps the lack of correlations between IAFT and STM reflects just that.

Nevertheless, the overall pattern of results concerning the IAFT and memory measures suggests that in both age groups enactment performance for actions did not correlate with any of the STM or WM measures. However, compared to children, who showed no reliable correlations between IAFT and STM performance, adults were able to utilise a variety of strategies to aid performance in verbal encoding. In other words, the WM correlations in adults, were observed for either actions after verbal encoding or for objects (in both enactment and verbal encoding). This raises the possibility that, rather than developmental

differences in action memory, it is the differences in WM functioning and resources that accounts for any differences in enactment performance between children and adults.

3.4.5 Summary

In summary, the experiments reported in this chapter suggest that enactment selectively facilitates order information for enacted actions in children and adults. Additionally, enactment facilitated item recognition for actions in adults. Further, these findings in combination with the existing literature on enactment effects in WM, provide some support for the claim that enactment in WM and enactment in LTM involve different mechanisms. This is because enactment in WM does not hinder order information at least at encoding. In order to provide further support for the assumption that enactment in WM and in LTM involve different processes however, item and order enactment benefits should also be examined in enactment recall.

Additionally, the experiments reported here suggest that compared to children, adults may be more flexible and efficient in their use of WM resources to facilitate performance. However, memory performance for actions after enactment encoding does not seem to depend on WM resources in either children nor adults. Together, these findings support the motor store hypothesis as the observation that, compared to verbal encoding, physical performance of actions enhances memory, and that this enactment advantage is unrelated to WM capacity, implies the involvement of motor processes.

Finally, although a few studies on enactment in WM have examined enactment at encoding (e.g. Allen & Waterman, 2015; Jaroslawska et al., 2016), a much larger body of WM literature has focused at enactment during recall (e.g. Gathercole et al., 2008; Yang, Allen & Gathercole, 2016; Yang, Gathercole & Allen, 2014). According to the literature, enactment at recall benefits rely on motor representations formed during encoding when anticipating future action (Koriat et al. 1990). In order to gain a better understanding of the mechanisms underlying enactment benefits, this project next investigated item and order

memory for actions and objects in enactment recall following verbal presentation. Therefore, the next chapter reports two experiments that examined enactment and the item-order hypothesis for actions and objects in WM when enactment was manipulated at recall only.

4 Chapter 4: Deconstructing the Enactment Effect II: Absence of action recall benefits raises questions regarding the nature of the enactment advantage.

4.1 Introduction

Chapter 3 reported two experiments that aimed to study item and order information under enactment in WM separately for actions and objects. The main findings suggested that actions were more likely to be recalled in the correct order after enactment encoding, while objects were recalled less accurately after enactment compared to verbal encoding. This pattern was evident in both children and adults. There are two main implications associated with this finding. First, the results show that the enactment effect at encoding is mainly driven by action words. This was indicated by the significant interaction between probe type and encoding which was observed in order reconstruction (Experiments 3 & 4), and in item recognition (Experiment 4). Second, it is suggested that enactment in WM and enactment in LTM might rely on different mechanisms. This is because, as compared to verbal encoding, enactment in WM both in the current studies and previous literature, seems to facilitate, or at least not hinder, order information. However, research on enactment in LTM has shown that order information is hindered under enactment compared to verbal and visual encoding (Schult et al., 2007). Therefore, this discrepancy between WM and LTM regarding order information and enactment may suggest that action memory in WM and LTM may on a different mechanism. Finally, no significant main effects of enactment encoding were observed in children or adults in the experiments reported in Chapter 3. This is a finding that partially contradicts previous literature (e.g. Allen & Waterman, 2015; Jaroslawska et al., 2016). The discrepancy in the findings between this project and previous research may be due to methodological differences as explained in Chapter 3.

Numerous studies on enactment and WM have focused on investigating enactment at the recall phase only (e.g., Gathercole et al., 2008; Yang, Gathercole & Allen, 2014) using whole action-object phrases. So far, the results presented in the previous chapters demonstrate some major differences to the existing enactment-WM literature. More specifically, examining separately action and object memory, (Experiments 1, 2, 3 & 4) seems to decrease the enactment advantage, yet some action benefit is still observed for action words. Therefore, in order to complete the investigation of the differential effects of enactment on action and object memory for item and order information, it is essential that an experiment should examine these factors at the recall phase.

4.1.1 Enactment Recall in WM

The benefits of enactment recall are thought to rely on a rich processing during encoding (Koriat et al. 1990). According to this view, when individuals know they will be asked to perform the instructions during recall, they recruit some form of action-motor plans during the encoding phase. In turn, this rich encoding representation leads to better memory performance during recall (Allen & Waterman, 2015). Indeed, Koriat et al. (1990) first established this phenomenon when they examined enactment recall for verbally presented material. As mentioned in Chapter 1 (section 1.1.2.2.), in Koriat's experiment participants were given a set of action-object phrases to memorise for subsequent enactment or verbal recall. Additionally, they were given a card informing them of the subsequent mode of recall (enactment or verbal) in each trial. Their findings showed that participants performed better under enactment recall compared to verbal recall. Crucially, the experiment also included some "surprise trials" in which the mode of expected recall did not match the actual recall mode. For instance, during encoding participants may have received a card indicating subsequent enactment recall but during actual recall participants were asked to verbally retrieve the material. It was observed, that when participants expected enactment recall (regardless of the actual recall mode), they performed better than when preparing for verbal

retrieval. The authors took this as further evidence to suggest that enactment recall benefits rely on a richer form of processing during the encoding phase in anticipation of action recall. This assumption was also supported by the findings of Allen and Waterman (2015), who found an enactment recall advantage when examining enactment and WM (see Chapter 1, section 1.3.1). They also concluded that enactment recall relies on a rich action-motor processing during encoding.

However, although enactment recall effects have been attributed to a rich form of encoding, including motor representations, the exact nature of these representations is not very clear. The literature on enactment and WM has presented two key findings that further the understanding of enactment recall benefits. The first is that the action-motor plans that lead to an enactment recall advantage do not rely on WM resources (Yang, Gathercole & Allen, 2014; Yang, Allen & Gathercole, 2016). Second, it is suggested that the action motor plans formed during encoding for later implementation are mediated by the motor store (Jaroslawska et al., 2018). These two interrelated assumptions are discussed in more detail below.

Yang et al. (2016) used the dual task paradigm to investigate whether disruption of the phonological loop, the central executive (Experiment 1) and visuospatial sketchpad (Experiment 2) during encoding would impair enactment recall performance. In the experiments reported in Yang et al. (2016), adult participants listened to instructions during encoding while engaging in a series of distractor tasks. More specifically, participants engaged in articulatory suppression (verbal distractor), backwards counting (central executive distractor) and spatial tapping (spatial distractor). The instructions were similar to Yang et al. (2014) (see Chapter 1, section 1.3.1). For instance, an example of instructions in one trial would be *“Touch the yellow ruler, and spin the red pencil, and push the blue ruler, and pick up the black pencil then put it into the blue folder”* (Yang et al., 2016, p.189).

The study employed a mixed design, whereby distractor task was a within-subjects factor and recall type (enactment vs verbal) was a between-subjects factor. The study examined memory performance in serial recall. In addition to overall performance, the authors also

analysed separately accurate memory for actions (i.e. movements) and for feature binding. In this case, feature binding described the successful recall of the correct action plus the correct object and the correct feature of that object (e.g. *touch the red pencil*). This scoring procedure enabled the authors to examine the linkage of features to each action, in other words to investigate action-object bindings.

The first experiment reported in this paper examined performance costs after articulatory suppression and backwards counting. The results showed a marginal effect of articulatory suppression in disrupting performance while backwards counting greatly impaired performance. This was the case in both verbal and enactment recall. Backwards counting also impaired feature linkage suggesting that the central executive plays a role in action-object bindings. Nevertheless, the enactment advantage over verbal recall remained evident in both distractor conditions. Furthermore, the authors reported that compared to verbal recall, enactment recall facilitated memory for actions as well as action-object bindings.

In their second experiment, Yang et al. (2016) added a visuospatial distractor task during auditory encoding aiming to disrupt VSP processing. The spatial tapping task required participants to tap a set of keys on a keypad in a specific order (i.e. 1-7-9-3). In this study, the disruption of the phonological loop led to a significant disruption of performance in both verbal and enactment recall. The phonological disruption was particularly evident in performance for the actions (i.e. movements). On the contrary, spatial tapping did not disrupt overall performance, but it did disrupt action-object bindings leading the authors to suggest that VSPWM plays a crucial role in linking actions to objects in the environment. This second experiment also showed that the enactment advantage over verbal repetition persisted despite the distractor tasks employed.

Overall, the study by Yang et al. (2016) showed that although enactment recall was disrupted equally to verbal recall by articulatory suppression and backwards counting, the enactment advantage remained intact. Furthermore, the study suggested that VSPWM as well as the central executive, play a role in action-object binding both in verbal and enactment recall. Finally, compared to verbal recall, enactment recall facilitated the binding

of information (i.e. action to object links) and additionally led to superior memory for actions per se. The authors concluded that the enactment advantage does not rely on WM resources as the benefits of enacted recall over verbal repetition persisted after each WM subcomponent disruption. These findings are also consistent with the results by Yang et al. (2014) (see section 1.3.1).

4.1.2 Motor store

In the absence of WM involvement in the enactment advantage, Yang et al. (2016) suggested that enactment benefits rely on the additional action-motor plans formed during the encoding phase, when there is anticipation for action recall. This provides further evidence for the motor store hypothesis which assumes that enactment benefits rely on motor processing.

Jaroslawska et al (2018), further examined the hypothesis that motor processing is the underlying cause of the enactment advantage. In this study (for the full study description see section 1.4.3), the motor distractor (Experiment 2), significantly impaired enactment recall performance, which suggests that enactment benefits rely on motor processing. The finding that the enactment advantage at recall is not affected by the depletion of WM resources (as a result of the distractor tasks), but is influenced by motor distractors, suggest that the enactment advantage relies on motor processing. Jaroslawska et al. (2018) postulate that the motor store is a system responsible for this type of motor processing and further suggest that the motor store is not independent of the WM system. The authors based this suggestion on the observation that motor distractors impair WM performance for action phrases, which in turn suggests that sensorimotor processes share processing resources with WM. More specifically, they suggest that the motor store is “a limited capacity system concerned with temporary retention of motoric, spatial and temporal features of intended actions” (Jaroslawska, 2018, p. 2246).

4.1.3 The present studies

So far, the evidence reviewed in this chapter suggest that the enactment advantage relies on the motor store, a system that processes motor, spatial and temporal information (Jaroslawska et al., 2018). The main evidence for this assumption originates in studies that have examined enactment during the recall phase for whole action-object phrases. In order to gain a better understanding of the action plans formed during encoding for future recall (and consequently the motor store), the experiments reported in this chapter, examined enactment at recall for action and object memory. Following the testing paradigm devised in the previous experiments of this project (i.e. the IAFIT), the current experiments examined action and object memory in enactment recall in children (Experiment 5) and adults (Experiment 6). One question of interest was whether the formation of action-motor plans during encoding for anticipated action recall would lead to better performance for the motor actions within the current paradigm. For instance, there is a possibility that the enactment benefit will be disrupted by the splitting of information at recall (i.e. action VS. object memory) as in Experiment 2. If the enactment advantage relies on purely motoric processing however, then it would be expected that a benefit of enactment recall would be observed for the motor actions.

4.2 Experiment 5

Enactment during the recall phase in children has been previously examined by Gathercole et al. (2008). In that study 5-year-old children listened to instructions for later action or verbal recall. The instructions were identical to Jaroslawska et al. (2016; 2018), whereby only two action phrases (pick up, touch) were used throughout all trials while objects and objects' colours varied across trials (for full description see Chapter 1, section 1.3.1). The findings from this study, indicated that enactment recall led to significantly greater performance compared to verbal recall. Additionally, this study reported a high correlation between backwards counting (as a central executive measure) and enactment performance. A similar pattern of findings was reported by Waterman et al. (2017) who followed the Allen and

Waterman (2015) paradigm by crossing enactment and verbal encoding and recall in children (see Chapter 2, section 2.1.1). In this study, enactment recall was superior to verbal recall performance after verbal encoding (Experiment 1). Additionally, as in Gathercole et al. (2008), enactment recall performance was highly correlated with BDR performance. Together, the findings from Gathercole et al. (2008) and Waterman et al. (2017) suggest that children's enactment recall performance seems to be more dependent on WM resources than it does in adults. Experiments with adults have mainly examined WM disruption and action performance, rather than examining the relationship between enactment and WM measures and therefore direct comparisons cannot be made. The current experiment aimed to examine memory for actions and objects in enactment during the recall phase in 8-year-old children. In addition, two types of memory were tested (following Experiments 3 and 4), order reconstruction and item recognition. Based on previous findings, it was hypothesised that compared to verbal recall, enactment recall would lead to better order information for the actions. Finally, verbal and visuospatial WM were also examined in order to test the relationship between action and WM performance in children.

4.2.1 Method

Participants

A total of 24 children were recruited from a local school. The mean age of participants was 8.31 years, $SD_{months} = 0.6$ (13 female, 11 male). Written consent was obtained from participants' parents prior to the study, and verbal consent was given by the participants on the day of testing. Students received stickers in exchange of their participation. The project was approved by the University of Bristol Faculty of Science Human Research Ethics Committee

Design

The study employed a 2x2x2 within-subjects design, with probe type (action, object), retrieval type (item or order memory) and response mode (enactment or verbal response) as

the independent variables. The dependent variable was accuracy and it manifested in two levels; for the order reconstruction trials, an item was scored as correct if that item was correctly identified and in the correct serial position. For the item recognition trials an item was scored as correct if it was part of the given trial independently of position. The enactment and verbal response conditions were completed in two separate blocks on two different days, while probe and retrieval type were manipulated within blocks. The order of the tasks was counterbalanced across days and conditions.

Materials

Instructed Action Task (IAFT)

A total of eight foam objects shaped as numbers and a total of eight action verbs were used as the stimuli for the IAFT. These were combined to create a total of 64 action-object pairs (i.e. *“shake the 1”*, *“push the 8”*). A total of two blocks of stimuli were created (A and B) so that participants would complete a different set of instructions under each retrieval mode condition. These were counterbalanced so that half of the participants completed Block A under enactment and the other half completed Block A under the verbal retrieval mode. Each block contained a total of 16 trials while each trial consisted of 4 action-object pairs. Therefore, each action-object pair appeared once in each block and twice throughout the experiment. The materials were pseudorandomised so that no action or object appeared twice in each trial or in exactly the same position in the previous or next trial. A total of 8 item and 8 order trials were presented per block. These were further divided so that half of them were action trials and the other half were object trials. The trials were pseudorandomised so that participants did not know whether at the end of the trial they would be asked to recall the actions or the objects and whether they will be asked to recall the items or the order.

A black card box (44 width x 27 height in cm) that contained the objects, was used during the recall phase (see Figure 4.1). The foam numbers were all the same size, weight and colour. Additionally, an orange foam ball was used to perform the actions in the enactment response condition. The box contained vertical and horizontal dividers, creating a total of 9

“pockets” each of which contained one object in a fixed position throughout the experiment. Since the experiment involved 8 objects and 8 actions, the top left square remained unused throughout the study. There was a space on the right side of the box (13.5 width x 27 height in cm) which contained the ball and participants were instructed to use that space to perform the actions (see Figure 4.1). In addition, a total of 18 “trial tops” for this box were created and each top was divided in 9 squares to match exactly the position of the 9 pockets underneath (including the “dead” top left corner). Two of the tops represented the item trials (one for actions and one for objects). For the object item trials, the trial top was built to expose all the numbers by carving out the 8 squares on the trial top (10 width x 9 height in cm, each), (see Figure 4.2). For the action item trials, the trial top displayed 8 pictures placed on the squares that matched exactly the position and dimensions of the objects underneath (see Figure 4.3). These pictures displayed each of the actions to be performed using the orange ball and included arrows indicating the direction of each movement as well as the name of each action (Arial, 16). For the order trials, a total of 16 tops were created (8 for actions and 8 for objects across the two blocks). These tops, were carved to leave exposed only four foam numbers if it was an object trial, or so that it displayed only four pictures with the actions if it was an action trial (see Figures 4.4 and 4.5). Each of these trial tops was different according to the stimuli to be recalled in each trial. The position of each foam object and each action picture on the trial tops and box remained stable throughout the experiment (for example the top right corner always contained the foam object 3 and was always the action “push”).



Figure 4.1. The box containing all the objects and the orange ball.

Working Memory

Participants also completed a Verbal and a Visuospatial Working Memory task. The Verbal Working Memory task (VWM) was identical to the one used in Experiment 4 (see Chapter 3, section 3.3.1). The task required participants to count the number of target objects (dogs) among distractors (cats) on each screen and to remember that number for later serial recall. The list length for this task was adapted for children thus ranged from 2 to 6 pictures per trial while participants completed 3 trials at each span level. As in Experiment 4, the task stopped if no trials were recalled correctly at a given span level. The experimenter sat on the left-hand side of the table and manually recorded participants' responses.

The Visuospatial Working Memory task (VSPWM) was identical to the VSPWM task used in Experiment 3. As with the VWM task, the list length for this task ranged from 2 to 6 pictures per trial while participants completed 3 trials at each span level. The task continued if the participant completed at least one correct trial at each given level. The task stopped if no trials were recalled correctly at a given span level.

For both tasks, the dependent variable was accuracy as measured in serial recall. This task was self-paced.

Procedure

Participants were tested in a quiet classroom in the school during school hours. They completed a total of two sessions lasting 30 minutes each, approximately one week apart. Each session involved one working memory task and one block of the IAFT. The type of working memory task (VSPWM, VWM), block of the IAFT (A, B) and the retrieval mode condition of the IAFT (Enactment, Verbal), were counterbalanced across days and participants. For example, participant 1 completed the VWM task and block A of the IAFT under enactment recall on Day 1 and the VSPWM task and block B of the IAFT as verbal recall on day 2, while participant 2 completed the VWM task and block A of the IAFT under verbal recall on day 1 and the VSPWM task and block B of the IAFT as enactment recall on day 2. The order of task completion per session was fixed throughout the experiment as follows. In session 1, participants started by completing the reading task (same as in Experiment 3, section 3.2.1), then moved on to the IAFT task and finally the WM task. In session 2, participants started with the WM task and then completed the IAFT task.

IAFT procedure

A laptop and the cardboard box were placed on a table directly in front of the participant. The experimenter sat on the right-hand side of the participant in order to switch the trial tops during the response phase. A camera was placed above the left side of the table facing downwards directly at the table. Participants started by completing the reading task and a set of practice trials prior to the IAFT. The practice trials were not fixed, but rather, each participant completed at least four practice trials, and if necessary, they continued till both the participant and the experimenter were confident that the participant understood the task and the procedure.

The stimuli were auditorily presented in Microsoft PowerPoint at a rate of 1200 ms per action-object phrase with a 2-seconds delay between each pair. During this time the screen remained blank. Participants passively listened to the four action-object phrases during encoding and were instructed to try and remember what they heard for later recall. The box was placed in front of the participant and the stimuli were hidden by a black card top throughout the encoding phase. At the end of each trial, a green star appeared on the screen to indicate the beginning of the response phase. The experimenter then removed the black cover top and placed the appropriate trial top on the box (that would be item or order for object or action recall). The response procedure varied according to response mode as outlined below.

Enactment response: At the end of each trial, the experimenter placed the appropriate trial top on the box (that could be either item or order and action or object top as these are described above). For the item-object trials, participants saw all of the numbers and were asked to recognise which 4 of those were presented in the last trial (see figure 4.2). They were instructed to do so by touching the four numbers in any order they wished. For the item-action trials participants saw all the possible actions and were asked to recognise which four of these actions were presented in the last trial (see figure 4.3). They were instructed to do so by performing the four actions in whichever order they wished, using the orange foam ball. For the order-object trials, participants saw only the four objects that were presented in the last trial and were asked to touch them in the right order (i.e., order of presentation) (see figure 4.4). For the order-action trials, participants saw only the four actions that were presented in the last trial and were asked to perform those actions on the ball in the right order (see figure 4.5). In this condition participants were discouraged from verbalising.

Verbal response: The procedure was identical to the enactment response but in this condition the participants had to verbally say the actions and objects in the item trials, and to verbally say the actions or objects in the correct order in the order trials (instead of touching the objects or performing the actions). The experimenter sat on the left-hand side of the table and manually recorded participants' responses.

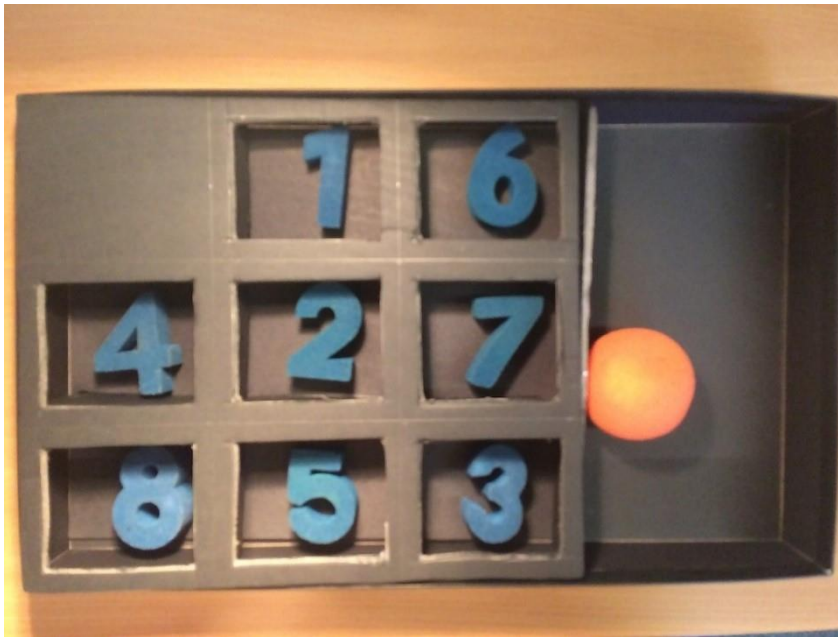


Figure 4.2. The response phase for object item recognition. In enactment recall participants were asked to indicate their response by touching the correct numbers (in any order they wished).

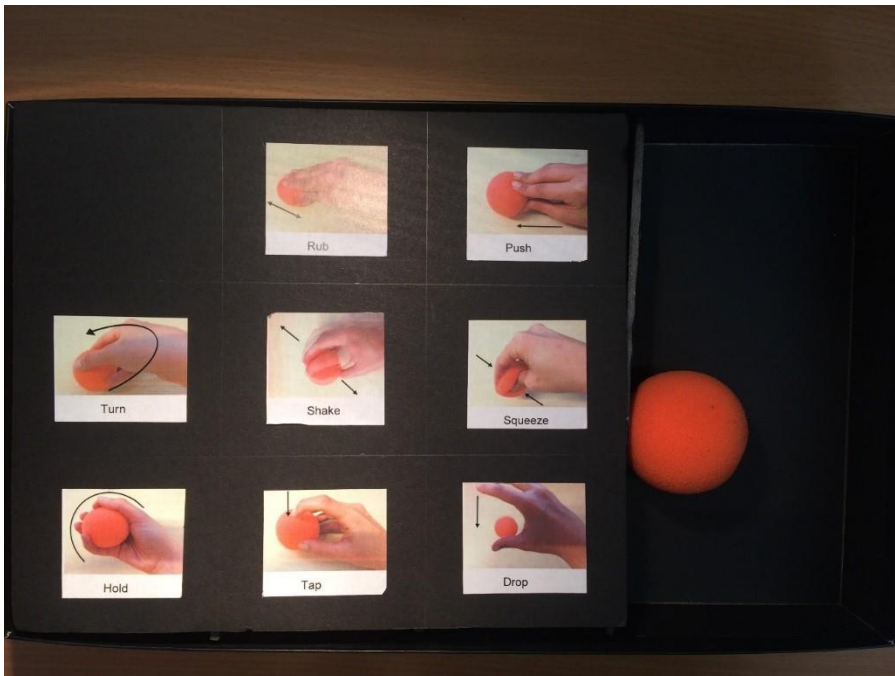


Figure 4.3. The response phase for action item recognition. In enactment recall participants were asked to indicate their response by performing the correct actions using the ball (in any order they wished).

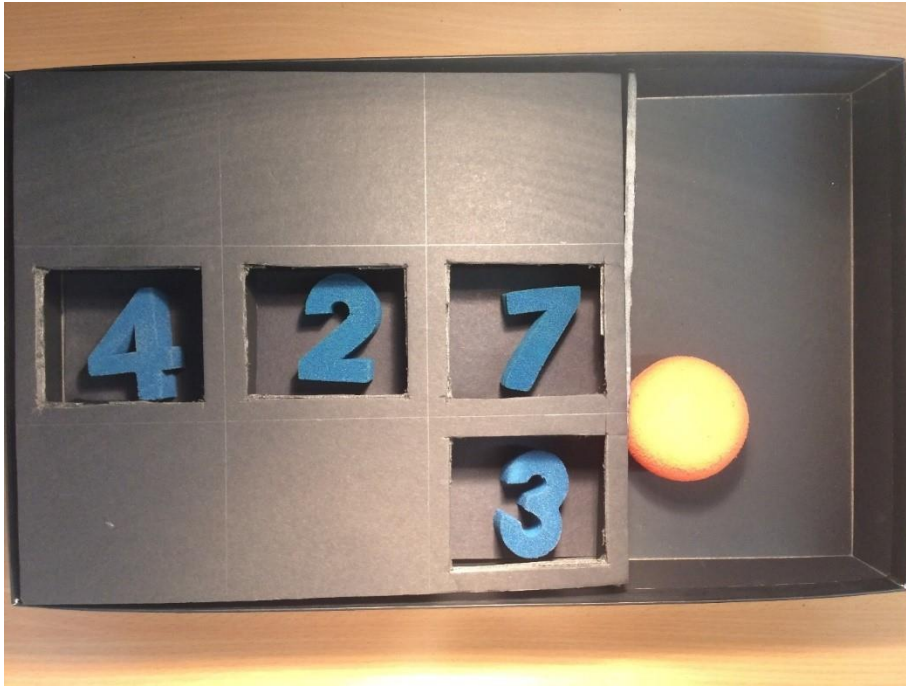


Figure 4.4. The response phase for object order reconstruction. In enactment recall participants were asked to indicate their response by touching the numbers in the correct order.

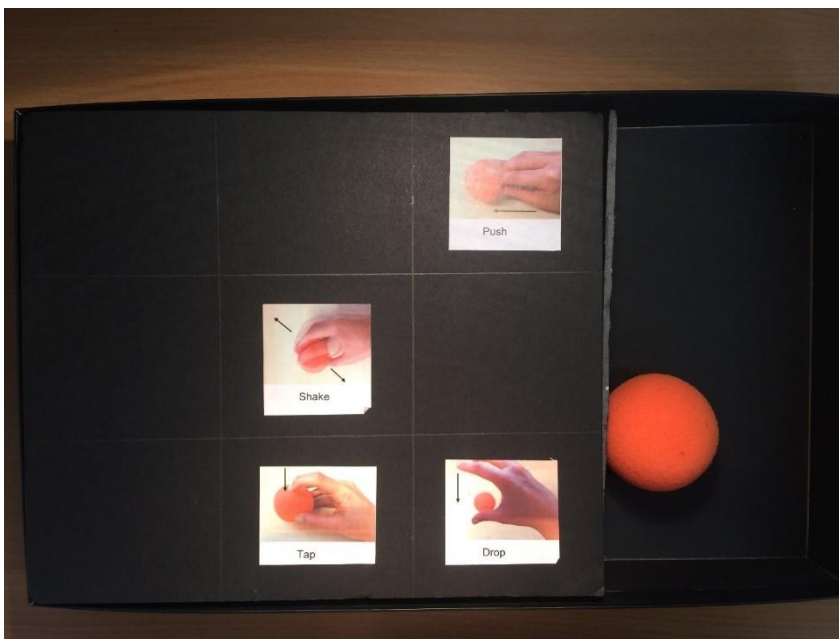


Figure 4.5. The response phase for action order reconstruction. In enactment recall participants were asked to perform the actions in the correct order.

4.2.2 Results

Scoring

The scoring procedure was identical to experiments 3 and 4 (see section 3.2.2). Descriptive statistics can be seen in table 4.1

Table 4.1 Means and standard deviations of performance in enactment and verbal recall for actions and objects in order reconstruction and item recognition.

Condition	Enactment		Verbal	
N=24	Actions (SD)	Objects (SD)	Actions (SD)	Objects (SD)
Order Reconstruction	0.39 (0.19)	0.51 (0.19)	0.38 (0.19)	0.48 (0.23)
Item Recognition	0.65 (0.11)	0.77 (0.12)	0.67 (0.10)	0.74 (0.11)

Item and order trials were analysed separately. Therefore, two 2x2 ANOVAS were carried out in order to explore the two levels of probe (actions vs objects) and the two levels of response mode (enactment vs verbal).

Order reconstruction memory

A 2 (probe) x 2 (response mode) repeated-measures ANOVA showed a significant effect of probe type $F(1, 23) = 8.832$, $p = .007$, $\eta^2 = .277$, showing a clear memory advantage for the objects over the actions. However, there was no significant effect of response mode $F(1, 23) = 0.220$, $p = .643$, $\eta^2 = .009$ suggesting that enactment did not benefit memory performance. The interaction between response mode and probe type was also not significant $F(1, 23) = 0.145$, $p = .707$, $\eta^2 = .006$. This suggests that response mode did not affect memory performance in a different manner for action or object recall (see Figure 4.6).

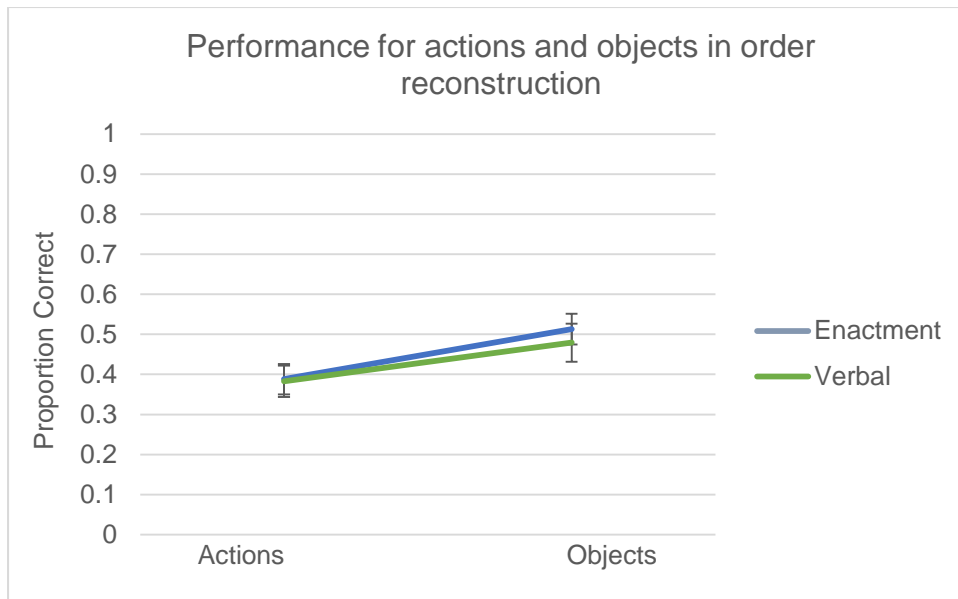


Figure 4.6. Order reconstruction performance for actions and objects in enactment and verbal recall. Error bars represent the standard error of the mean.

Item recognition memory

A 2 (probe) x 2 (response mode) within-subjects ANOVA showed a significant effect of probe type $F(1, 23) = 21.959, p < .001, \eta^2 = .488$ with objects been more accurately recalled than actions, but no significant effect of response mode $F(1, 23) = 0.083, p = .776, \eta^2 = .004$ showing that enactment did not benefit item memory. The interaction between response mode and probe type was also not significant $F(1, 23) = 1.105, p = .304, \eta^2 = .046$ (see Figure 4.7).

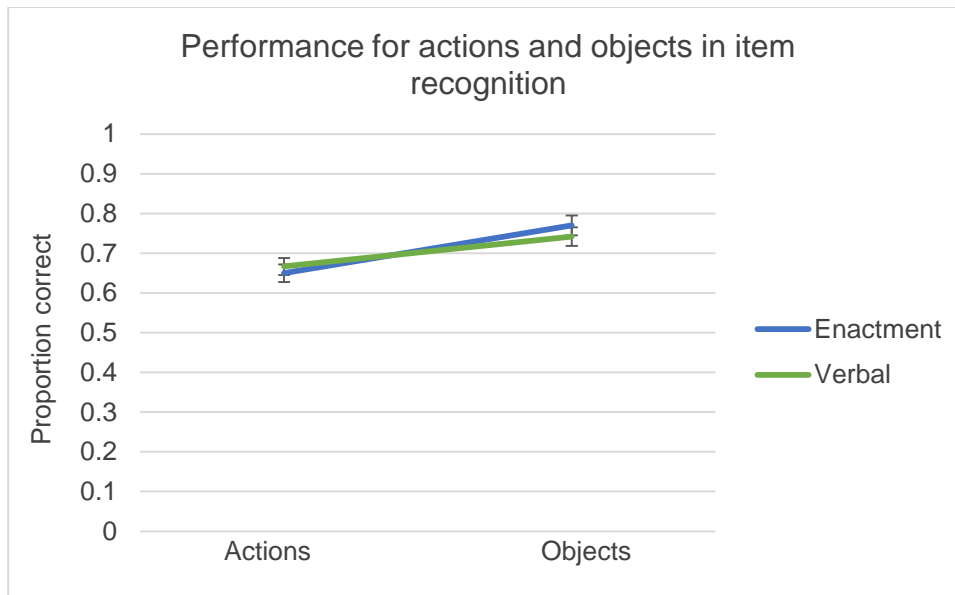


Figure 4.7. Item recognition performance for actions and objects in enactment and verbal recall. Error bars represent the standard error of the mean.

Bayesian Analysis

It is possible that the null effects observed in this study are due to the small sample size and therefore the null results might reflect a lack of power to detect any effects. A Bayesian analysis was carried out in order to explore further the nature of the findings. While null hypothesis testing is based on a reject or fail to reject assumption, this Bayesian approach directly evaluates the strength of evidence for the null and the alternative hypotheses and the extent to which each of the hypotheses are supported by the data. In other words, calculating the Bayes factor, enabled the direct testing of the likelihood that the null hypotheses is supported rather than non-rejected (Masson, 2011).

Therefore, the estimate of the Bayes factor and the posterior probabilities for retrieval mode and the interaction between retrieval mode and probe were calculated using the computations provided by Masson (2011). The Bayes factor and the posterior probabilities for the alternative and null hypotheses for each condition can be seen in the table 4.2 below.

Table 4.2. The Bayes factor (BF01) and the posterior probabilities for the null hypothesis $p(H0|D)$ and the alternative hypothesis $p(H1|D)$ for the item and the order conditions.

Order Memory	BF01	$p(H0 D)$	$p(H1 D)$
Retrieval Mode	4.38	.81	.19
Retrieval Mode*Probe	4.54	.82	.18
Item Memory			
Retrieval Mode	4.60	.82	.18
Retrieval Mode*Probe	2.78	.74	.26

Note: probability values above .74 indicate positive evidence for the model (Raftery, 1995).

As it can be seen in table 4.2 the evidence points in favour of the null hypothesis suggesting that retrieval mode did not affect performance in the order or the item trials. Additionally, the retrieval mode did not influence differently performance for the actions or the objects in either order reconstruction or item recognition. Taken together, both analyses suggest that enactment did not lead to better recall for the actions or the objects in item recognition or order reconstruction.

Correlations

Working Memory for both WM measures partial credit scores were calculated. A Pearson's correlation revealed a reliable correlation between the two tests $r = .526$, $p = .008$. The correlations between the IAFT conditions and the two WM tasks can be seen in the table below (table 4.3).

Table 4.3. Correlations between performance for the actions and the objects in item recognition and order reconstruction under enactment (E) and verbal (V) recall and WM performance.

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.21	.21	.36	.30
VWM and objects	.17	.10	.47*	.41*
VSP WM and actions	.55**	.19	.05	.12
VSP WM and objects	-.25	.10	.10	-.02

For the order trials, the only significant correlation was found between enactment recall performance for the actions and Visuospatial WM. On the contrary, in the item trials it was verbal WM that correlated significantly with object memory in enactment and verbal recall. As can be seen in the table above, action memory in the item trials also correlated to some degree with verbal WM although this correlation failed to reach significance perhaps due to the small sample size.

4.2.3 Discussion

Experiment 5 aimed to examine action and object memory at enactment recall in children. Based on previous findings, it was expected that memory for actions would be greater in enactment recall compared to verbal repetition. However, the results showed no reliable effects of enactment on memory for actions or objects in either order reconstruction or item recognition. These results contradict previous research that has repeatedly observed enactment recall benefits in children (Gathercole et al. 2008; Jaroslawska et al., 2016; Waterman et al., 2017). However, there are a few major differences between the current study and those in the previous literature. First, the studies that have observed enactment recall benefits in children have examined the enactment of whole action-object phrases. The current study distinguished action and object memory at recall and perhaps this manipulation hindered any enactment benefits. In addition, the objects in previous studies remained visible throughout the experiment while in this study the objects were hidden during encoding. Finally, in the case of Gathercole et al. (2008) and Jaroslawska et al. (2016) the material consisted of meaningful action-object phrases with potential long-term associations. Perhaps, the lack of main enactment effects in this experiment is partly due to a combination these methodological differences.

However, these differences cannot completely account for the null results in this experiment as the current findings are also not consistent with Experiment 1 (Chapter 2, section 2.2.2) in which an enactment recall benefit was observed for actions in children.

Experiments 1 and 5 used the same instructions and in both studies participants were asked to recall either the actions or the objects. However, there are four main differences between Experiment 1 and this study. First, in this experiment, all stimuli were hidden during the encoding phase minimising the chances of visuospatial encoding or the reliance on cues in the environment. In Experiment 1 the objects remained visible during the encoding phase, which perhaps enabled participants to form visuospatial plans for later enactment recall.

The crucial role of VSP encoding in aiding enactment performance in children has been demonstrated before. More specifically, Jaroslawska et al. (2016, for full description see Chapter 1, section 1.3.1) found that compared to verbal and enactment encoding, orthographic encoding eliminated the enactment recall advantage. In this orthographic encoding condition, participants heard and then read each instruction on a computer screen. The authors suggested that participants' focus on the screen did not allow for visuospatial encoding during presentation and this in turn impaired enactment performance. The assumption that visuospatial encoding is a contributing factor to the enactment advantage in children is also supported by Waterman et al. (2017). In all three experiments they reported in their paper, they found that superior enactment compared to verbal recall in children, strongly correlated with VSPWM. Thus, it is suggested that VSP encoding plays a defining role in enactment recall performance in children. The current experiment, as well as Jaroslawska et al. (2016) show that limiting VSP information or opportunities for VSP encoding potentially eliminates the enactment recall advantage.

The second difference is that in the current study, recall consisted of either item recognition or order reconstruction. This may have affected the findings for two reasons. First, the two separate retrieval modes in the recall phase may have posed additional task demands, adding one more step in the retrieval process. That is, participants at the end of the trial would be informed whether they needed to recall the actions or the objects presented and additionally whether they should recall them in order reconstruction or item recognition. This procedure may have been too complex for children. However, if the enactment advantage does not rely on WM processing as previously implied, then the

enactment advantage would still be evident, despite an overall decrease in performance. The second reason for the discrepancy between previous findings and this study with regards to item-order information is that Experiment 1, in line with the previous literature, found enactment recall effects in WM when examining serial recall. Order reconstruction and serial recall involve different mechanisms (Gathercole et al., 2001) and it has been shown that enactment effects differ in order reconstruction and serial recall (Engelkamp, Jahn & Seiler, 2003).

Third, in Experiment 1, in the equivalent condition (verbal encoding-enactment recall) participants had a 4 second delay between each action-object phrase during which they verbally repeated the instructions. Perhaps this gave participants extra time to elaborate on the to-be-remembered items whether in verbal or motor form. In the current paradigm, participants silently listened to the instructions which were presented consecutively with no delay between each action-object pair. Thus, the pace of presentation in this experiment may have reduced the possibilities for elaboration or rehearsal. In previous studies with children, there is typically a delay between each action-object pair presentation (e.g. Waterman et al. 2017).

The final difference between Experiment 1 and the current study is that in this study, during the recall phase, participants saw the actions in visual and written form while in Experiment 1 only the objects were displayed throughout the experiment. The visual display of actions during recall was added in this experiment in order to provide even and balanced action and object retrieval cues. However, it may well be, that the display of actions during recall led to some form of interference thus hindering any enactment benefit. This point will be further discussed in the general discussion section of this chapter.

The findings regarding WM suggest a different pattern for order and item trials. It is important to note that item and order trials as well as action and object trials were pseudorandomised. Therefore, differences in the correlations between item and order memory and WM cannot be attributed to differences in strategy use for different types of recall during encoding. In other words, participants were not aware of the type of recall until

the end of the trial and, thus, it cannot be argued that they selected an encoding strategy based on the nature of recall (item-order) or the stimuli (action-object). Rather, it seems that different subsystems of WM are related to performance in the item and order trials as well as to action and object memory.

More specifically, action order reconstruction in enactment recall significantly correlated with VSPWM. Perhaps this correlation reflects the processes involved in this recall condition, that is, the mental reordering of actions from the visual display while simultaneously performing them. On the other hand, recalling the objects in order did not involve as much visuospatial resources because participants were only asked to touch the numbers in the correct order, not physically perform them as the actions. Performance for object item recognition in enactment and verbal recall significantly correlated with Verbal WM. Action item recognition in both enactment and verbal recalled seem to relate to Verbal WM performance although this did not reach significance perhaps due to the small sample size. This may suggest the involvement of both verbal and central executive resources to aid performance. However, since performance rates were similar under both recall conditions, no firm conclusions can be made regarding the role of WM in aiding enactment performance.

Overall, the findings from this experiment suggest that in the current paradigm, enactment recall in children failed to increase memory performance for actions or objects in item recognition or order reconstruction. The reasons for this are not clear but perhaps as explained above a combination of differences between the current methodology and previous research may have contributed towards the results. Nevertheless, these results are very informative as understanding what eliminates the enactment effect may prove useful in understanding its underlying mechanisms. Further, examining enactment recall in adults may provide additional information regarding the lack of enactment effects in the current paradigm.

4.3 Experiment 6

4.3.1 Introduction

Experiment 6 aimed to examine action and object memory in enactment recall in adults using the IAFT. As in Experiment 5, recall had two levels, item recognition and order reconstruction. Previous research examining enactment recall in adults, has shown superior memory for action events even in the presence of distractors during encoding (Yang, Gathercole & Allen, 2014; Yang, Allen & Gathercole, 2016). Based on previous findings, it was expected that compared to verbal recall, enactment would lead to better order and item information for the actions in adults.

4.3.2 Method

Participants

Forty psychology university undergraduate students ($mean_{age}=20.31$ $SD_{months}=1.79$) took part in the study in exchange of course credit. Participants completed the experiment in one session lasting approximately 50 minutes.

Design

As with Experiment 5, the study employed a 2x2x2 within-subjects design, with probe type (action, object), retrieval type (item or order memory) and response mode (enactment or verbal response) as the independent variables. The enactment and verbal response conditions were completed in two separate blocks, while probe and retrieval type were manipulated within blocks. The dependent variable was accuracy and it manifested in two levels. For the order trials, an item was scored as correct if it was the correct item and in the correct position. For the item trials, an item was scored as correct if it was present in that trial independently of its position. The order of the tasks was counterbalanced across participants.

Materials and Procedure

IAFT

The materials used in this experiment were identical to Experiment 5 but with the following modifications in order to adjust task difficulty. The IAFT consisted of a total of 10 foam objects (0-9) and 10 action verbs (instead of 8 used in Experiment 5). A total of two blocks were created, each containing 16 trials. Each trial consisted of 5 action-object pairs. Each action-object pair appeared a maximum of once in each block and once or twice throughout the experiment. Therefore, a new card box was created to fit 10 pockets for the 10 objects (see Figure 4.8). Dimensions were similar to Experiment 5 except from the ball container (45 width x 9 height in cm). In all other respects the procedure and material were identical to Experiment 5.



Figure 4.8. The experiment box modified for Experiment 6.

Working Memory

The VWM task was identical to that used in Experiment 5 in terms of material and procedure but slightly modified to adjust task difficulty in the following manner; the list length ranged from 3 to 10 pictures per trial, while each screen displayed a total of 12 objects (targets and distractors). The ratio of targets and distractors in each picture varied in each trial. As with Experiment 5, the task stopped when the participants failed to recall correctly any of the three trials at a given level.

The VSPWM task was identical to Experiment 5 in terms of general procedure, however the material and list length were modified to increase task difficulty. The main stimuli (pink sheep, black sheep and pink elephants) were swapped for geometrical shapes (black circles, grey circles and black ovals respectively) (see Figure 4.9). An example of the response screen can be seen below (see Figure 4.10). This change was deemed necessary as in the Experiment 5 version of this task, the visual search for the target was too trivial for adults (it did not require any effort to identify the target). Without active visual search for the target object this task resembles a STM task rather than a WM task as it does not involve any additional processing during presentation. Furthermore, the list length ranged from 3 to 10 pictures per trial and each picture displayed 12 objects (1 target and 11 distractors).

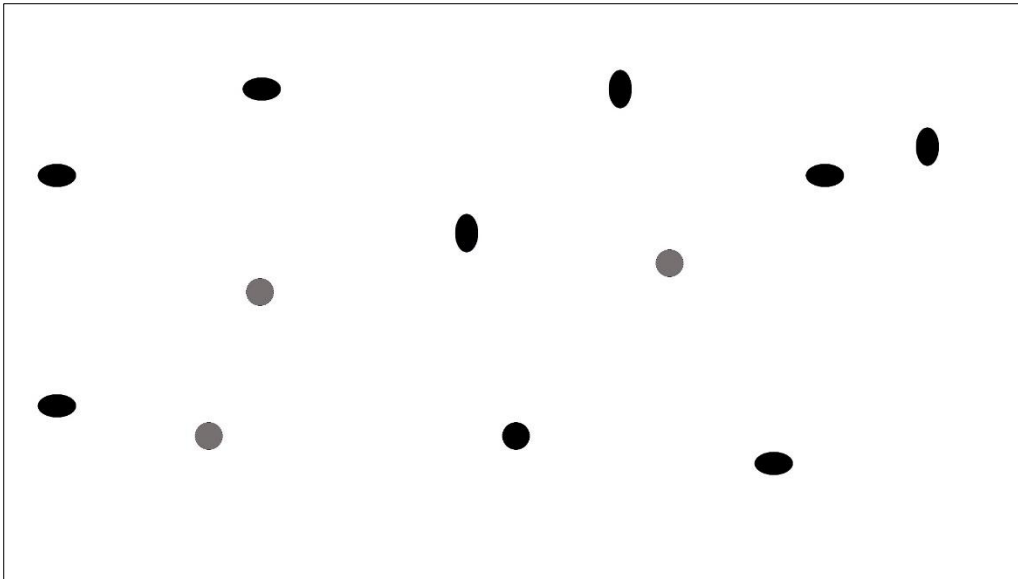


Figure 4.9. Example of a screen in the VSPWM task. Participants had to find the circle and memorise its location before moving to the next screen. Trial length ranged from 3 to 10 screens per trial.

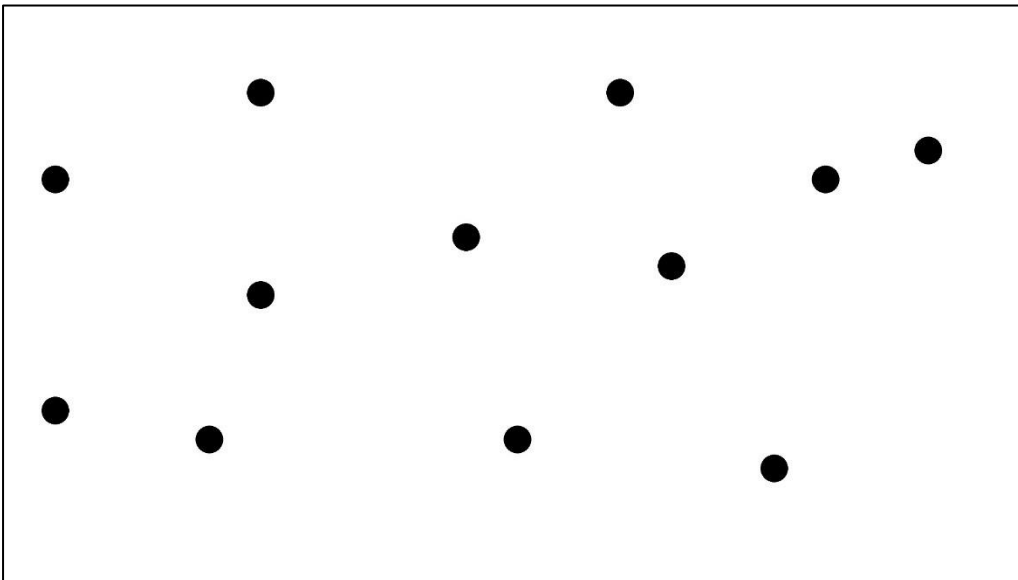


Figure 4.10. Example of the response screen in the VSPWM task. Participants had to click on the black circle locations that corresponded to the initial position of each circle in each screen of that trial in the correct order.

4.3.3 Results

Scoring

The scoring procedure was identical to experiments 3 and 4 (see section 3.2.2).

Descriptive statistics can be seen in Table 4.4. Item and order trials were analysed separately. Therefore, two 2x2 ANOVAS were carried out in order to explore the two levels of probe (actions vs objects) and two levels of response mode (enactment vs verbal).

Table 4.4. Mean recall accuracy for action and object memory in item recognition and order reconstruction under enactment and verbal recall.

Retrieval Type	Enactment		Verbal	
	Actions (SD)	Objects (SD)	Actions (SD)	Objects (SD)
Order	0.48 (0.15)	0.59 (0.20)	0.46 (0.16)	0.59 (0.18)
Item	0.77 (0.09)	0.85 (0.07)	0.76 (0.08)	0.83 (0.08)

Order reconstruction memory

A 2 (probe) x 2 (response mode) within-measures ANOVA showed a significant effect of probe type $F(1, 23) = 30.605$, $p < .001$, $\eta^2 = .440$, but no significant effect of response mode $F(1, 23) = 0.197$, $p = .660$, $\eta^2 = .005$. The interaction between response mode and probe was also not significant $F(1, 23) = 0.099$, $p = .755$, $\eta^2 = .003$ (see Figure 4.11).

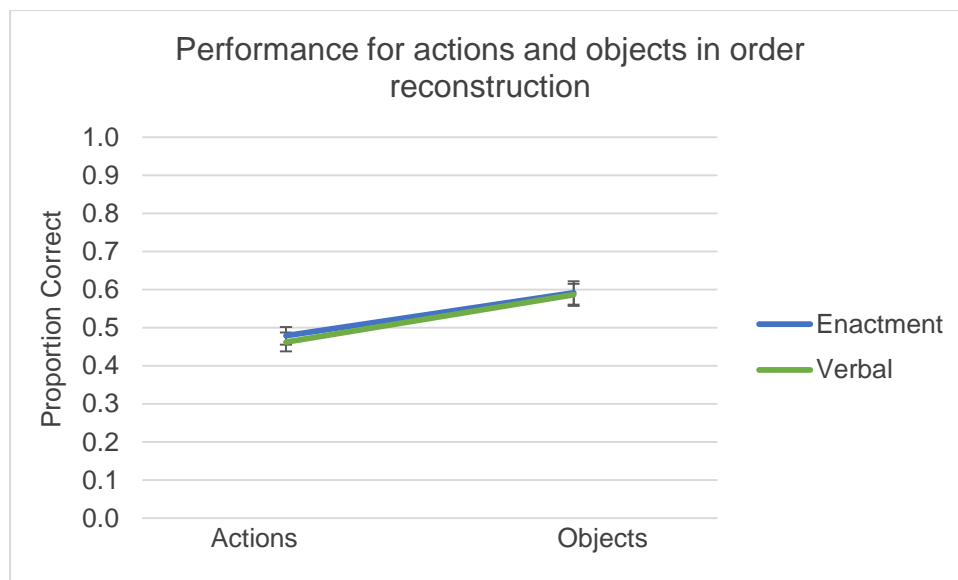


Figure 4.11. Order reconstruction performance for actions and objects in enactment and verbal recall. Error bars represent the standard error of the mean.

Item recognition memory

A 2 (probe) x 2 (response mode) within-measures ANOVA showed a significant effect of probe type $F(1, 23) = 45.378$, $p < .001$, $\eta^2 = .538$ but no reliable effect of response mode $F(1, 23) = 0.832$, $p = .367$, $\eta^2 = .021$. The interaction between response mode and probe was also not significant $F(1, 23) = 0.163$, $p = .688$, $\eta^2 = .004$ (see Figure 4.12).

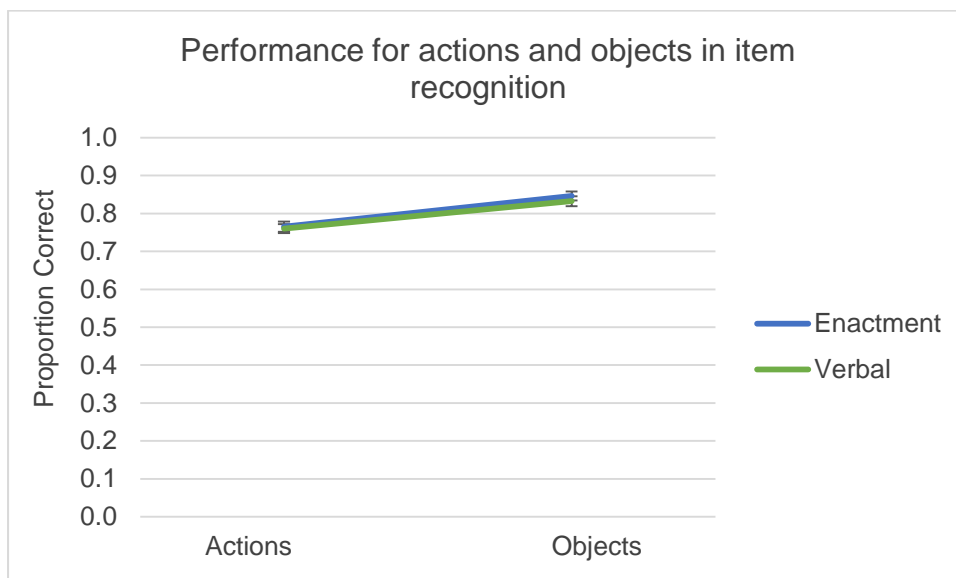


Figure 4.12. Item recognition performance for actions and objects in enactment and verbal recall. Error bars represent the standard error of the mean.

As in Experiment 5, the Bayes factors and posterior probabilities for the null and alternative hypotheses were also calculated as shown in table 4.5 below.

Table 4.5. The Bayes factor (BF_{01}) and the posterior probabilities for the null hypothesis $p(H_0|D)$ and the alternative hypothesis $p(H_1|D)$ for the item and the order conditions.

Order Memory	BF01	p(H0 D)	p(H1 D)
Retrieval Mode	5.60	.84	.15
Retrieval Mode*Probe	6.00	.85	.14
Item Memory			
Retrieval Mode	3.92	.79	.20
Retrieval Mode*Probe	5.62	.84	.15

Note: probability values above .74 indicate positive evidence for the model (Raftery, 1995).

As can be seen in table 4.6, the evidence points in favour of the null hypothesis suggesting that enactment did not meaningfully affect performance in order reconstruction or item recognition. Additionally, the retrieval mode (enactment-verbal) did not influence differently performance for the actions or the objects in the order or the item memory tasks. Taken together, both analyses suggest that enactment did not lead to better recall for the actions or the objects in item recognition or order reconstruction.

WM Correlations

Both verbal and visuospatial WM correlated with significantly with performance in certain enactment and verbal recall conditions (see table 4.6). More specifically, Verbal WM correlated significantly with performance in both enacted and verbal recall for item and order memory for actions and objects. The only exception was enactment recall for actions in the item trials. VSP WM correlated with actions only in the verbal recall condition and with objects in all conditions except order memory with verbal recall.

Table 4.6. Correlations between performance for the actions and the objects in order reconstruction and item recognition under enactment (E) and verbal (V) recall and WM performance.

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.36*	.41**	.16	.49**
VWM and objects	.58**	.32*	.50**	.52**
VSP WM and actions	.16	.36*	.01	.26
VSP WM and objects	.34*	.21	.53**	.46**

Regression analysis

The high correlations between the IAFT and both WM measures suggests that either both visual and verbal WM separately contributed to performance, or that a common underlying component of the two WM tasks (e.g., central executive functioning) predicts IAFT

performance. In order to investigate this further, a set of linear regressions was performed for each IAFT IV with VWM and VSPWM as separate predictors of performance. This enabled the calculation of the shared variance of the two WM tasks in predicting performance for the different types of trials. In order to do this, two linear regression analyses were performed for each IV, whereby the Verbal WM was entered as the independent measure first (variable A) and the VSP WM was entered next (variable B). This showed the R^2 change when variable B was added. The regression was then repeated but with VSPWM (variable B) entered first, and Verbal WM (Variable A) entered second. This gave the R^2 change when variable A was added. In turn, this enabled the calculation of the shared variance (C) by adding the R^2 change for Variables A+B and then subtracting this sum from the total variance of the model (total variance= A+B+C). So that the final calculation would be A+B+C – (A+B)=C. The results can be seen in table 4.7 below.

Table 4.7. Regression analysis showing the individual contributions of each WM task and the contribution of shared variance between the two WM tasks to each IAFT condition. Total model values are also shown.

		Variance Explained			Predictors (VWM+VSPWM)	
	ORDER	Verbal WM	VSP WM	Shared Variance	F value	p
Enactment	Actions	10%*	0%	2%	2.751	0.077
	Objects	23%**	3%	9%	9.555	<.001
Verbal	Actions	7%	3%	11%*	4.484	0.018
	Objects	6%	0%	4%	2.137	0.132
ITEM						
Enactment	Actions	3%	1%	-1%	0.596	0.566
	Objects	6%	10%*	19%*	9.705	<.001
Verbal	Actions	18%*	0%	7%	5.927	0.006
	Objects	10%*	4%	17%*	8.606	0.001

The full model with both WM tasks as predictors significantly predicted performance in both enactment and verbal recall but with the following exceptions; verbal recall for the objects under order reconstruction and enactment recall for the actions under both order

reconstruction and item recognition. Working Memory did not reliably predict performance for these variables.

As the significance of shared variance cannot be tested directly, assumptions regarding the level of significance of the shared variance are based on the fact that similar or lower percentages of unique variance explained were significant. For example, Verbal WM predicted performance for the actions in enactment and this effect was significant ($R^2=.10$) thus the shared variance of ($R^2=.11$) that was observed for actions in verbal WM should also be significant. As can be seen in the table above, the shared variance of the two WM tasks seems to be associated with performance in both enactment and verbal conditions as a function of probe. More specifically, the shared variance seemed to predict performance for the objects in both enactment and verbal item recognition (and marginally in enactment order reconstruction). For the actions, the shared variance seemed to be involved in performance only in verbal order reconstruction.

4.3.4 Discussion

The aim of Experiment 6 was to examine the effects of enactment recall for action and object memory in item recognition and order reconstruction. The findings showed that enactment at recall did not benefit performance for actions or objects. This was evident in both item recognition and order reconstruction. These results are in agreement with Experiment 5, where no meaningful enactment recall effects for actions or objects were found in children. The results are not consistent with the literature that has observed enactment recall benefits in adults (Allen & Waterman, 2015), even in the presence of distractor tasks aimed to disrupt performance at encoding (Yang et al., 2014; Jaroslawska, 2018). As mentioned in the discussion of Experiment 5, there are several methodological differences that may account for this finding. These will be re-examined in the general discussion section of this chapter. In terms of WM associations, performance in the IAFT task correlated with Verbal WM as well as VSPWM. The general picture shows that Verbal

WM was strongly associated with overall performance in the IAFIT suggesting that participants relied on verbal memory to aid performance, a finding that was also confirmed in the regression analysis. More specifically, the regression showed that Verbal WM independently predicted memory performance in enactment order reconstruction and item verbal recognition (for both actions and objects). Visuospatial WM mostly correlated with item and order memory performance for the objects in both conditions, and with actions only for verbal order reconstructions. These findings indicate that adult participants relied on both domain specific and domain general processes to aid performance. This was evident in item recognition memory for objects under both enactment and verbal recall and for actions in verbal reconstruction. Thus, the regression analysis suggests that if there is an involvement of the central executive then this is mainly evident in performance for objects under both recall conditions as indicated by the shared variance values. On the contrary, performance for actions under enactment did not seem to involve central executive resources. This finding is consistent with previous literature (Jaroslawska et al. 2018; Yang et al., 2016) that has suggested that enactment does not depend on central executive resources. The difference between this study and previous research however is that enactment did not increase recall performance. The general discussion of this chapter explores these issues in more detail.

4.4 General discussion

4.4.1 Summary of findings

The aim of Experiments 5 and 6 was to explore further the underlying effects of enactment by examining enactment at recall in children and adults, using the action vs object paradigm established in this project. It was expected that memory for actions would benefit from enactment compared to verbal recall. However, the results did not show any enactment benefits for actions or objects in either children or adults. As discussed above, these results are not consistent with previous research. The main speculations regarding this discrepancy are discussed in turn below.

4.4.2 Interpretation of findings and limitations

One explanation for these findings is that splitting the action-object information during the recall phase by asking participants to recall either the actions or the objects inhibited the formation of action-motor plans during encoding. This seems to have been the case in all the experiments reported in this thesis to some extent, but it has been more evident in Experiments 5 and 6. In the case of action recall under enactment in these experiments participants had to perform the actions using the orange ball, while the instructions during encoding referred to performing each action on a specific object. This manipulation was essential in order to examine the effects of enactment for purely motor actions vs. objects but it seems that it hindered any benefits of enactment. For instance, if the enactment advantage at recall relies on action-motor plans formed during encoding, changing the instructions from encoding (e.g., shake the 3) to recall (shake the ball) may have disrupted those action-motor plans. Thus, participants may have relied on verbal strategies in both recall conditions instead. This would explain why performance was virtually identical in both enactment and verbal recall, showing seemingly no effects of the retrieval type manipulation. In the adult sample (and partially in children), this assumption is supported by the correlations between enactment performance and verbal WM suggesting that participants relied on verbal memory in this condition. Evidence that discrepancies between encoding and recall may impair enactment performance was provided by Koriat et al. (1990). In that study they observed that when the expected recall mode did not match the actual recall mode (e.g., when participants expected to enact at recall but were given a verbal test instead), performance significantly dropped compared to when expected and actual recall mode matched. This suggests that contextual differences between encoding and recall can impair enactment performance.

Another factor that may have influenced performance is that the stimuli were not visually available during encoding. This may have further hindered visuospatial planning and mental imagery during encoding as explained in the discussion for Experiment 5 above (e.g. see

Experiment 1 in Jaroslawska et al., 2016). However, it should be noted that Yang, Allen, and Gathercole (2016), examined enactment recall performance in adults after instructing participants to close their eyes during auditory encoding and they still observed an enactment benefit. However, in Yang et al. (2016) participants' self-reports revealed that most participants imagined performing the actions during encoding in this condition (but note that verbal rehearsal was also quite common). Perhaps, this further suggests that within the current paradigm, inhibiting action-object binding by splitting action and object information at recall, disrupted the formation of action-motor plans during encoding.

One other possibility is that within the current paradigm, retrieving actions while performing them may have led to motor interference. For instance, previous research has suggested that memory for single actions is disrupted when accompanied by motor movements (Shebani & Pulvermuller 2013). In their study, Shebani and Pulvermuller (2013) asked participants to remember action verbs related to either hand or leg movements while simultaneously performing a motor sequence either with their hands or legs. They observed that overall performance was disrupted when participants performed motor movements. Crucially, they found that the interference was stronger when the action verbs in the memory list were related to the same part of the body as the motor sequence performed. If physical performance of actions interferes with memory for action verbs, then it is likely that the variety of hand movements performed in the experiments reported in this chapter led to memory interference for the instructions.

Motor interference may have not been evident in previous enactment studies for two main reasons. First, all WM-enactment studies have examined memory for action-object phrases. The action-object bindings in those studies may have facilitated recall, minimising the effects of interference, especially since objects' shapes, colour, weight and function varied. For example, both instructions *pick up the pen* and *pick up the envelope* involve the action word *pick*, however, the motor movement of *picking* is slightly different when picking a pen to when picking an envelope. Thus, by binding the action to a specific object, the participant may create a richer representation of each instruction phrase, moving away from merely

motoric processing. Indeed, Yang et al. (2016), who examined action-object links, reported that participants exhibited excellent feature binding as when the correct action was recalled it was followed almost always by the correct object.

The second factor that may have led to motor interference in the current studies, was that participants also had visual access to motor movements during recall as they saw the actions in both pictorial and written form. This may have led to greater motor interference as this condition involved mentally retrieving the correct items, processing the available actions in the environment and physically performing the correct actions almost simultaneously. The availability of actions at recall perhaps also led to greater need for inhibition of incorrect responses.

In the case of action vs object memory, the current findings are consistent with the results from Chapters 2 and 3, showing again that memory for objects was superior to memory for actions. Given that actions in Experiments 5 and 6 were available during recall like the objects, this suggests that memory superiority for objects observed in previous experiments is not due to the fact that objects were available in the environment. Alternatively, it may be that in the experiments reported here the availability of the actions during recall impaired performance to a greater extent for actions than objects (as speculated above) hence the difference in recall rates.

Finally, there is the possibility that lack of power may be responsible for the absence of any enactment effects in the present studies. As in chapter 3, the current experiments included a limited number of trials per condition (four trials). Additionally, the sample size in Experiment 5 was fairly small to conduct a reliable correlation analysis. Thus, the present findings should be interpreted with caution due to the lack of power to detect any reliable effects.

4.4.3 Conclusions

The findings from Experiments 5 and 6 suggest that adults and children exhibited very similar patterns of performance in the IAFIT, showing no noticeable effects of enactment. In terms of WM, children's performance did not show a strong pattern of correlations between the WM tasks and the IAFIT or any evidence for central executive involvement. The absence of evidence for central executive involvement is not consistent with previous research that observed strong correlations between the central executive and enactment recall in children (see Gathercole et al., 2008; Waterman et al., 2017). However, the absence of reliable correlations between WM and IAFIT in children was accompanied by the absence of main enactment effects therefore no conclusions can be made regarding the involvement of WM resources in the enactment advantage. Given the pattern of correlations between IAFIT and WM in children and adults, it may be assumed that adults made greater use of WM resources to aid performance in the main task compared to children. However, since meaningful enactment effects were not observed in either age group, no speculations can be made regarding the role of WM in the enactment advantage or the nature of the motor store.

Nevertheless, overall the results support the assumption that the benefits of enactment rely on a rich representation of actions and object pairings, visuospatial information and long-term associations rather than simple motor benefits. This is because splitting the representation of action-object phrases seems to hinder the formation of motor action plans that are thought to underlie enactment benefits at recall. In the case of motor interference, again it may be assumed that selectively attempting to retrieve only the motor actions without any contextual information hinders performance. Therefore, it is suggested that enactment superiority relies on rich processing rather than simply a motor benefit for action words. These assumptions will be further discussed in detail in the next chapter.

5 Chapter 5: General Discussion

5.1 Project objectives

The current project aimed to investigate the underlying mechanisms of the enactment effect within the WM paradigm. Previous research has established that performance of instructions in immediate recall is superior to verbal learning in adults and children (Allen & Waterman, 2015; Jaroslawska et al., 2016) and that this effect is independent of WM resources, at least in adults (Yang et al., 2014). The objective of this project was to gain a better understanding of this enactment superiority by deconstructing instructions to their basic components (actions, objects) in order to examine which elements of instructions benefit most by physical performance. Past research, both in LTM and WM, has examined memory for instructions that involve whole action-object phrases. A key innovation of the current project was that it examined separately memory for actions and objects under enactment or verbal encoding and recall in six experiments involving children and adults. It was expected that physical performance will facilitate memory recall predominantly for actions when it was employed either at encoding or at recall. This prediction was based on previous research (e.g. Yang, Gathercole & Allen, 2014) as well as the assumption that physical performance would enhance memory for the motor actions performed rather than other information (e.g. object identity). This is because the most prominent view assumes that enactment benefits rely on motor plans and processes (Engelkamp & Zimmer, 1989; Jaroslawska et al., 2018; Smyth & Pendleton, 1989). Finally, the enactment effect in this project was examined from a developmental perspective, with studies recruiting both children and adult participants in order to gain a better understanding of the action memory system underlying enactment. More specifically, a question of interest was whether motor-action memory improves with age in a similar fashion to WM (e.g. Foley & Johnson, 1985) or whether it remains stable across development (Cohen & Stewart, 1982).

The first two experiments examined verbal vs. enactment memory at both encoding and recall using the paradigm devised by Allen and Waterman (2015) in children (Experiment 1) and adults (Experiment 2). These studies investigated the effects of physical performance on memory for actions in all four possible combinations of enactment and verbal encoding and recall in both children and adults. The difference to previous research was that in the present project an additional manipulation was employed whereby participants had to recall either the actions or the objects presented. The aim was to identify specific enactment effects for actions to be examined in more detail in subsequent experiments. Based on the findings of this study, the next four experiments examined enactment at encoding (experiments 3 and 4) and enactment at recall (Experiments 5 and 6) for item recognition or order reconstruction in children and adults. The next section summarises the findings from each experiment for the Instructed Action Task (IAT) followed by a summary of the findings regarding the relationship between enactment and WM measures.

5.2 Key findings

5.2.1 Enactment

The first two experiments that crossed enactment and verbal encoding and recall showed that both children and adults benefited from enactment for the actions. However, a different pattern of enactment benefits was found for the two age groups. Specifically, children exhibited superior memory performance under enactment retrieval for actions in serial recall, while adults showed enactment encoding benefits for actions, an effect that was evident in both free and serial recall. Memory for objects also showed enactment benefits but these were manifested in a different manner in children and adults. Children showed an enactment encoding benefit for objects which was evident only in free recall. Adults' object memory benefited from enactment encoding when the recall was verbal and benefited from verbal encoding when the recall was enacted but not when encoding and recall modes were

enacted. This interaction between encoding and recall modes was observed only in the serial recall analysis.

This diverse pattern of findings regarding memory for objects in the two age groups indicated that there may be developmental differences in the way children and adults benefit from enactment. This is because memory for objects in adults was superior when encoding and recall modes were different, while in children a benefit for object memory under enactment was observed at encoding independently of recall mode. Finally, memory for objects showed enactment benefits when examining serial recall in adults and free recall in children. Additionally, the observation that enactment benefits for actions were seen in serial recall in both adults and children was consistent with enactment studies in WM but not LTM. Furthermore, previous studies of enactment in WM have examined memory for action-object phrases, yet the current project split action-object memory and found that the enactment advantage in serial recall was observed more prominently for actions in both age groups. This was a novel finding, which offered the potential for further investigation. This is because previous research examining whole action-object phrases has shown that enactment does not benefit order information (Olfsson, 1995), particularly for actions (Koriat et al., 1990). The first two experiments of this thesis however, that split memory for actions and objects, found benefits of enactment for actions in serial recall which implies that actions may carry order information. In order to examine directly the relationship between enactment, order information and memory for actions in WM, the next studies in this project examined two types of recall; item recognition and order reconstruction. Due to the complexity of the task and experiment length limitations, enactment at encoding and enactment at recall were split across 2 groups of experiments. These examined enactment at encoding and enactment at recall respectively in children and adults.

Experiments 3 (children) and 4 (adults) that examined enactment at the encoding phase only, found that enactment hindered order information for objects but facilitated order information for actions. This finding, observed in both children and adults, manifested as a significant interaction between encoding and probe type. Additionally, the same interaction

was observed in adults for item recognition, whereby action performance was superior after enactment compared to verbal encoding. Finally, an analysis of order information within the item trials in children also revealed the same interaction between encoding mode and probe type. Thus overall, this clear trend of enactment benefits for actions, and the consistency of the pattern across age groups provides strong evidence that enactment does not hinder, and may even facilitate, order information. Crucially this effect was specific to memory for actions not objects. These findings are consistent with Experiment 2, in which enactment encoding led to superior performance for actions in adults in both serial and free recall.

Finally, Experiments 5 and 6 aimed to complete the overall investigation by examining item recognition and order reconstruction at enactment during recall. As in the previous experiments, enactment was studied using the IAFI which separated action and object memory at recall. Additionally, recall type had two levels, order reconstruction and item recognition. Contrary to predictions and previous research, no meaningful effects of enactment were observed in children (Experiment 5) or adults (Experiment 6) in item recognition or order reconstruction. Performance in order reconstruction and item recognition was very similar in both verbal and enactment recall conditions for actions and objects. Contrary to Experiment 1, Experiment 5 did not find a benefit for actions in enactment recall in children. There were several methodological differences between the two experiments that may be responsible for this discrepancy, discussed in detail in chapter 4 (section 4.2.3). For adults, the null findings in Experiment 6 are consistent with Experiment 2, where no enactment recall effects were observed for the actions.

5.2.1.1 Key remarks

Across the 6 experiments, there was therefore some evidence that enactment facilitated memory for motor actions when employed at encoding (Experiments 2, 3 & 4) and at recall (Experiment 1). Thus, the overall pattern of findings suggests that, to some extent, enactment benefits rely on motor processing since it was mainly the actions that benefited from enactment performance. However, no clear enactment main effects were observed in

Experiments 3, 4, 5 and 6 which contradicts previous research (Allen & Waterman, 2015; Jaroslawska et al., 2016; Waterman et al., 2017) suggesting that the enactment advantage is not purely the result of additional motor processing. For instance, the null findings observed in the last two experiments (Experiments 5 and 6) are of particular interest as they indicate that the motor plans formed during encoding when expecting enactment recall were interrupted. There is the possibility that the splitting of action-object information at retrieval, contributed to the elimination of the enactment advantage. If this is the case, then it shows that enactment benefits do not rely solely on motor memory but also on complex representations that include action-object bindings. It has been previously argued that motor planning and action preparation is relative to the object to be acted upon (Tucker & Ellis, 2001). For example, upon viewing a tea cup, one will activate the precision grip specific to that object.

Perhaps this suggests that motor plans, presumably formed during encoding, are beneficial when a very specific, clear representation can be formed. For instance, when the instructions encoded correspond perfectly to the instructions to be performed at recall. The fact that in the current project participants encoded a set of instructions corresponding to a specific object (e.g. *push the 1*) but at recall they were required to *push the ball*, may have led to interference that interrupted the motor plans that would otherwise lead to accurate performance. For example, it has been shown that when participants judge an action that is incongruent with their own motor response participants' judgment is impaired (Glenberg & Kaschak, 2002). In this experiment, participants heard action sentences and had to make a judgement with respect to whether the sentence was a sensible one (e.g. open the drawer) or a nonsense sentence (boil the air). Further, for the sensible condition, two types of stimuli were constructed; action phrases with an implied direction towards one's body (e.g. open the drawer) or away from the body (e.g. close the drawer). Participants had to judge the sense of each presented sentence by making a movement away from the body to indicate the sentence was sensible (by pressing a button further away from them), or towards their body to indicate it was not (by pressing a button closer their body). Finally, this button

manipulation was reversed half-way through the experiment so that participants had to indicate a yes response by pressing the button closer to their body and a no response by pressing the button away from their body. Reaction times in this task revealed that participants took longer to make a judgement when the sentence's implied movement was incongruent with the movement they had to perform to indicate their answer. For instance, judging the sentence "open the drawer" as sensible in the first half of the experiment took longer than the sentence "close the drawer". This is because the former was incompatible with the response movement (open the drawer involves a movement towards the body but to respond they had to make a movement away from the body). On the contrary, confirming the sentence "close the drawer" implies movement away from the body thus it is compatible with participants' forward movement they had to make to indicate the correct response.

The findings from this study suggest that the mere processing of motor phrases may interfere with actual motor movement if the two are incongruent. In a similar vein, the two competing actions during recall in this project (i.e. shake the 3 vs. shake the ball) may have reduced the enactment advantage. This is because according to this account (Glenberg & Kaschak, 2002), exposure to an action phrase results automatically in a mental simulation of the corresponding motor movement (for the sentence to be comprehended). In turn, if the motor movement that is to be performed in relation to this action sentence is incongruent with it (e.g. roll the 6 vs roll the ball), performance is disrupted. Thus, this account provides support for the assumption that the difference in action-object pairings between encoding and recall may be partly responsible for the elimination of the enactment recall advantage in Experiments 2, 5 and 6 of this project.

Finally, the observation that the enactment advantage was reduced to a greater extent when enactment was manipulated at recall than when it was employed at encoding raises the possibility that the two process may differ. In other words, throughout the six experiments of this thesis, it seems that the splitting of action-object phrases impaired to a greater degree enactment recall than it impaired enactment encoding. This may suggest that enactment at

encoding and enactment at recall may involve different mechanisms. These theoretical implications will be discussed in more detail in section 5.3 below.

5.2.2 Enactment and WM

All the correlations between the IAFT and WM and STM performance can be seen in tables 5.1 to 5.6 below. Overall, the correlations between WM/STM tasks and memory for motor actions in all 6 experiments suggest the following pattern; for both children and adults, action memory performance after enactment encoding did not correlate reliably with STM or WM performance (Experiments 1, 2, 3 & 4). On the contrary, memory for actions in enactment at recall correlated significantly with STM (Experiment 1), Verbal WM (Experiment 6) and VSPWM (Experiment 5).

Table 5.1. Experiment 1. Correlations between STM capacity and memory performance in the four conditions for actions and objects in children.

STM and Probe	Condition			
	EE	EV	VE	VV
STM and actions	.29	.31	.59**	.55*
STM and objects	.12	.10	.44*	.18

Table 5.2. Experiment 2. Correlations between STM capacity and memory performance in the four conditions for actions and objects in adults.

STM and Probe	Condition			
	EE	EV	VE	VV
STM and actions	-.03	-.07	.39	.47*
STM and objects	-.22	-.06	.09	.02

Table 5.3. Experiment 3. Correlations between performance for the actions and the objects in item recognition and order reconstruction after enactment and verbal encoding and the additional memory measures (STM and Visuospatial Working Memory) in children.

STM, WM and Probe	Order		Item	
	E	V	E	V
STM and actions	.32	.05	-.22	.23
STM and objects	.11	-.04	.05	.04
VSP WM and actions	-.20	.16	.18	.25
VSP WM and objects	.38*	.10	.28	.05

Table 5.4. Experiment 4. Correlations between performance for the actions and the objects in item recognition and order reconstruction after enactment and verbal encoding and the additional memory measures (Verbal and Visuospatial Working Memory) in adults.

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.09	.04	.04	.39*
VWM and objects	.00	.21	.36*	.43**
VSP WM and actions	.29	.19	.22	.42**
VSP WM and objects	.45**	.22	.04	.26

Table 5.5. Experiment 5. Correlations between performance for the actions and the objects in item recognition and order reconstruction under enactment and verbal recall and WM performance in children.

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.21	.21	.36	.30
VWM and objects	.17	.10	.47*	.41*
VSP WM and actions	.55**	.19	.05	.12
VSP WM and objects	-.25	.10	.10	-.02

Table 5.6. Experiment 6. Correlations between performance for the actions and the objects in item recognition and order reconstruction under enactment and verbal recall and WM performance in adults.

WM and Probe	Order		Item	
	E	V	E	V
VWM and actions	.36*	.41**	.16	.49**
VWM and objects	.58**	.32*	.50**	.52**
VSP WM and actions	.16	.36*	.01	.26
VSP WM and objects	.34*	.21	.53**	.46**

This pattern of correlations is partially consistent with the literature. Developmental studies that report correlations between enactment and WM performance have shown that WM mechanisms are related to both enactment encoding and enactment recall. More specifically, enactment performance in children at both encoding (Waterman et al., 2017) and recall (Gathercole et al., 2008; Waterman et al., 2017) was associated with measures assumed to tap both the Central Executive (BDR task) as well as simple verbal WM (FDR task). Similarly to Experiment 1 (but also see Experiment 5), in this project, enactment recall after verbal encoding in both Gathercole et al. (2008) and Waterman et al. (2017) correlated to a meaningful extent with simple verbal WM. Additionally, in Experiment 1 of Waterman et al. (2017), performance in enactment encoding with enactment recall, did not correlate meaningfully with simple verbal WM performance, a pattern that was similar to Experiment 1 of this project (Table 5.1). Finally, as in Experiment 3 of this project, in Experiment 2b of Waterman et al. (2017) enactment encoding with verbal recall did not correlate reliably with simple verbal WM performance.

Additionally, Waterman et al. (2017) found that enactment encoding performance related to VSP WM as measured by the Corsi task in Experiment 3 but not Experiment 1. The difference between the two experiments in that previous study was that Experiment 1 used a total of 6 action words while Experiment 3 used only two (push, lift). Perhaps the difference

in the correlations between enactment performance and the Corsi task between the two studies reflects a difference in strategies employed by the participants. When motor actions were minimised to two items, participants may have relied on means other than motor processing to remember the instructions such as focussing on visuospatial locations and visual processing of the objects.

Overall, the correlations between enactment and WM performance in children, both in the aforementioned studies and in this project, exhibit some differences and inconsistencies between experiments (see for example Experiment 1 vs. Experiment 3 in Waterman et al. 2017) and between studies (see differences in correlations between verbal recall and WM in Gathercole et al. vs Waterman et al.). Nevertheless, the overall picture suggests that in children, enactment performance correlates to WM capacity. More specifically, both Gathercole et al. (2008) and Waterman et al.(2017) showed strong correlations between enactment performance and the BDR task, assumed to tap the functioning of the central executive (which was not examined in the current project). A further finding that consistently emerged in both of these previous studies and this project is that enactment at recall performance correlates reliably with STM (Experiment 1).

The relationship between WM performance and enactment in adults has also been studied using the dual task paradigm (e.g. Jaroslawska et al., 2018; Yang et al., 2014; Yang et al., 2016). As mentioned in previous chapters, those studies suggest that the enactment advantage in adults does not depend on WM resources. The present project found that enactment encoding performance did not correlate significantly with measures of WM, but the correlations between enactment at recall and WM performance (both verbal and visuospatial) suggest that to some extent, performance in the IAFT and in the WM tasks rely on the same mechanisms.

A consistent finding across experiments in this project was that enactment encoding performance for the actions did not correlate reliably with any WM measures in children or adults (EXP 1, 2, 3 and 4). Enactment at recall correlated to a reasonable degree with action performance for order reconstruction in children (VSP WM) and adults (VWM) (Experiments

5 and 6). These findings suggest that enactment recall may rely more heavily on WM resources, as the findings from Gathercole et al. also imply. However, since the correlations between IAFT conditions and WM are relatively inconsistent, possibly due to the small sample sizes recruited in this project, it is not possible to make any strong claims or draw strong conclusions regarding the relationship between enactment performance and working memory.

In order to be able to make direct comparisons between children and adults regarding the relationship between WM and enactment, future studies should employ a dual task paradigm in children. For instance, future research should examine whether the enactment advantage observed using whole action-object phrases is still evident after WM distractors are introduced during encoding in children as it has been shown in adults. This will allow for direct comparisons of the two age groups regarding the enactment advantage and its reliance on WM resources.

5.2.3 Actions Vs Objects

In all experiments, objects were significantly more likely to be recalled than actions in all conditions. This finding is consistent with previous enactment research which has coined the term noun-superiority effect to refer to this phenomenon (Engelkamp et al., 1990). However, overall enactment benefited memory for actions more than objects, an effect that is also consistent with the literature (e.g. Engelkamp et al., 1991; Koriat et al., 1990; Yang, Gathercole & Allen, 2014). Furthermore, action and object memory exhibited different patterns of performance in order reconstruction as a function of encoding type (Experiments 3 and 4). In order reconstruction, actions benefited from enactment encoding while object performance was superior after verbal encoding. This pattern was evident in both children and adults. In addition, in adults, enactment encoding led to more accurate memory for actions in item recognition compared to verbal encoding while verbal encoding led to better object memory in those item trials. Therefore, it is suggested that overall physical

performance at encoding enhances memory for actions, while memory for objects does not benefit from enactment to the same extent. On the contrary, enactment may even lead to poorer performance for objects than verbal learning, at least within the current paradigm (Experiments 2, 3 and 4).

5.2.4 Developmental differences

Throughout the six experiments, adults showed higher rates of performance than children both for enactment and verbal encoding and recall despite the list length adjustments for difficulty. This shows that even with the attempted adjustment for difficulty, adults still found that the task easier than children and so the difficulty of the IAFT was not perfectly equated across these groups. The fact that adults outperformed children even on longer lists implies unsurprising developmental changes but does not in itself provide any further insights regarding the nature of these developmental differences. However, more may be learnt from the enactment effects pattern observed in this project as explained below.

Although the first two experiments showed slightly different patterns in the enactment advantage between children and adults, performance in the subsequent experiments (3,4,5 & 6) showed very similar patterns for the two age groups. In terms of the relationship between IAFT and WM, the overall pattern of correlations suggests greater WM involvement in the IAFT for adults than children (see tables 5.1-5.6). Together, these findings suggest that differences in IAFT performance rates may be due to developmental differences in WM, while the mechanisms related to enactment (e.g. motor planning) do not differ between 8-year-old children and adults. This is because the same effects and interactions were observed in the two age groups in Experiments 3, 4, 5 and 6. Thus it is suggested that enactment affects performance in a similar manner in these age groups implying that motor systems (or their interaction with higher cognitive mechanisms) remain relatively stable across development.

5.2.5 Enactment and the Item-Order Hypothesis in WM

The examination of the item-order hypothesis in enactment encoding (Experiment 3 and 4) and enactment recall (Experiments 5 and 6) in WM showed the following pattern; enactment enhanced order (Experiment 3 and 4) and item memory (Experiment 4) for actions when it was employed at encoding, but it did not provide additional benefits for order or item memory when recruited at recall (Experiments 5 and 6). It should be noted that although enactment did not benefit order information at recall in Experiments 5 and 6, it also did not hinder performance. Previous studies of LTM have suggested that enactment hinders order information leading to overall poorer performance compared to verbal conditions (Engelkamp & Dehn, 2000) and to observation (Schult et al., 2014). Thus, based on this suggestion, enactment should have impaired memory in order reconstruction. However, Experiments 5 and 6 showed that performance was very similar in enactment and verbal recall conditions. Although this is not sufficient evidence to suggest that enactment in WM involves different mechanisms to enactment in LTM, the overall pattern of the current findings provides promising ground for future investigations.

The pattern suggesting that physical performance at encoding facilitates order information for actions but not objects, is a novel finding (Experiments 2, 3 and 4). This effect may reflect the fact that, in everyday life, motor tasks typically involve an ordered sequence of movements facilitating goal directed behaviour, rather than single actions (Tanji, 2001). Additionally, order memory for motor sequences, contrary to other types of memory, can be acquired via an implicit form of learning (Ashe et al., 2006). In other words, sequential information for motor movements does not always require cognitive effort to memorise. This may explain why enactment at encoding enhanced action order reconstruction but enactment at recall did not facilitate order information for actions. More specifically, the physical performance of the motor sequence at encoding may have led to the formation of an implicit motor sequence schema (i.e. motor learning) that facilitated accurate order

reconstruction at recall (Engelkamp & Zimmer, 1995). On the contrary, auditory encoding for future enactment recall should, according to the literature, rely on motor planning processes (Koriat, 1990). However, if the motor plans were either unable to be formed or interrupted due to the action-object separation at recall, this may have led to the elimination of any motor advantage. Further, perhaps the inability to rely on motor planning may have led participants to memorise the action sequences verbally. This type of strategy would rely on explicit and effortful encoding of order information. This assumption is supported by the relationship between enactment performance and verbal WM in adults (see table 5.6).

Therefore, the difference between order reconstruction performance for the actions in enactment encoding and recall further suggests that the enactment advantage at encoding relies on different processes than enactment at recall. For example, it has been suggested that memory for performed motor sequences can be an implicit form of learning that does not require explicit awareness of the acquisition of such knowledge (Ashe et al., 2006; Willingham, Nissen & Bullemer, 1989; Willingham, Wells, Farrell & Stemwedel, 2000) and further evidence suggest that this type of processing is located and mediated in the motor cortex (Nitsche et al., 2003). The implicit learning of motor sequences within this paradigm has been mainly studied using variations of the Serial Reaction Time Task (SRTT). In this task, participants see four squares on the screen (in four different locations). A stimulus will then appear in one of those squares and depending on which square it appears in, the participant would need to make a different response on the keypad. Thus, each of the four possible locations a stimulus could appear in corresponds to a different key-press on a touchpad. In this task a series of sequences are presented that are repeated every few trials but not consecutively so to avoid explicit learning (e.g. 2134, 4123, 1432, 2431, 2134, 1243).

In this task the dependent variable is reaction time so that sequences that have been encountered in the past result in faster response times. Crucially, this type of learning is thought to be implicit, because when participants complete explicit memory tests regarding the sequence learning their performance does not correspond to the actual task

performance (Nitsche et al., 2003; Willingham et al., 1989). In other words, they are not explicitly aware of the learning that has occurred.

It is possible that enactment encoding results in a similar form of implicit learning of the motor sequence. Thus, it may be argued that physical performance reinforces the linkage of motor movements, that is, sequential information. As in the SRTT, this would involve motor, spatial and temporal information bound in a unified representation. According to this assumption, motor performance at encoding would involve implicit *learning*, while enactment at recall involves motor *planning* at encoding for future implementation. Whether these two processes are dependent on the same mechanisms (e.g. the motor store), is yet to be investigated.

5.3 Interpretation of findings and theoretical implications

5.3.1 Evidence for different motor processes at enactment encoding and enactment recall

The current project was the first to examine the different effects of enactment encoding and enactment recall for actions vs objects in WM. The main findings suggest that overall this manipulation weakened the enactment effect in both children and adults. However, this design was necessary in order to examine the separate effects of enactment for actions and objects, and for the specific benefits to memory for actions to be observed. A number of novel key findings emerged by splitting the action-object information at recall. More specifically, the overall pattern of findings in the 6 experiments reported in this thesis showed that enactment favoured predominantly memory for actions, not objects. Moreover, this enactment advantage was mainly observed at encoding, not at recall. Together, these findings suggest that motor processes play a major contributing factor to the enactment advantage at least when instructions are performed during encoding. Additionally, the current project provided evidence that contrary to verbal presentation, enactment encoding leads to superior order reconstruction memory for actions. This novel finding further supports

the assumption that enactment benefits rely partially on motor processing, as it was memory for the performed, not the verbally repeated, actions that exhibited greater order reconstruction performance.

In addition, based on the pattern of the overall results, it is suggested that enactment encoding and enactment recall involve slightly different processes (see also Nyberg et al., 2001 in Chapter 1, section 1.4.2). In more detail it is suggested that enactment encoding benefits involve *motor learning* while the enactment recall advantage is based on *motor planning*. For example, in Experiments 3 and 4, the physical performance of motor actions during encoding might have led participants to store the sequence of actions in motor form in an implicit or automatic manner, leading to greater memory performance in this condition (order reconstruction). The absence of similar benefits at enactment recall suggests that implicit order (i.e. sequential) information for actions is beneficial mainly when accompanied by actual physical performance (i.e. when introduced at presentation).

Motor planning for future implementation (enactment at recall) may also involve the activation of motor schemas (e.g. Jeannerod, 2000), but the present results show that in order to be effective, these schemas have to match contextually between encoding and recall. In other words, the object on which the action is to be performed, defines the action itself and in consequence, it also defines the motor plan that will be formed during encoding. For example, the motor action of lifting will be different depending on the object to be lifted (e.g. lifting a cup vs. lifting a book) (Kormi-Nouri & Nilsson, 2001). The current studies show that when there is a mismatch between encoding and recall, for instance when the action-object binding changes from encoding to recall (i.e. tap the 8, tap the ball), the enactment recall advantage is eliminated. On the contrary, memory representations of motor movements that have been already physically performed sequentially at encoding carry inherently that order information. This motor order information is then spontaneously manifested at retrieval, perhaps without explicit awareness (see for example order reconstruction of actions within item trials in Experiment 3).

In turn, it is suggested that the damage inflicted by the splitting of action-object information during retrieval is not as destructive when enactment is manipulated at encoding compared to when it is manipulated at recall. This is because after enactment encoding the action-object binding information is not so crucial anymore, as the action has already been performed (realised) during encoding. In other words, physical performance concretises the encoded motor action (Engelkamp et al., 1991; Kormi-Nouri & Nilsson, 2001). In contrast, the action-object binding is crucial during actual encoding, when forming motor plans for future enactment recall. This is because, as mentioned above, the form the action itself will take will depend on the object on which the action is to be performed. Thus, the enactment recall advantage ultimately depends on the successful action-object binding during encoding.

Further evidence for this assumption can be found in the study by Kormi-Nouri, Nyberg and Nilsson (1994) which investigated enactment and verbal encoding and recall for well-integrated and poorly-integrated action-object phrases (Experiment 2). In this study, participants encoded well-integrated pairs (e.g. write with the pen) or poorly-integrated pairs (look at the candle) via enactment or verbally. The recall phase was again either enactment or verbal. They found that enactment encoding led to superior performance than verbal encoding for both well and poorly integrated pairs. Enactment recall, however, was severely impaired when the items were poorly integrated, particularly after verbal encoding. This finding supports the assumption that enactment encoding and enactment recall rely on different processes (Kormi-Nouri et al. 1994) and that action-object bindings play a more important role for successful enactment recall than for enactment encoding.

Overall the findings in this project support the idea that enactment encoding and enactment recall may involve, at least to some extent, different motor processes. This assumption is also supported by the correlations between WM capacity and the IAFT. Throughout the six studies, STM and WM measures did not correlate meaningfully with enactment encoding performance for actions, for neither children, nor adults. Enactment recall however, showed links to both STM and WM measures in both age groups. This

pattern of findings supports the idea that memory for enacted actions at encoding may be relatively automatic, involving implicit learning in motor form. In contrast enactment at recall requires more effortful cognitive involvement at least when action-object information differs between encoding and recall phases.

Given that enactment superiority is a well-established effect in the literature, it is possible that the absence of strong main effects in this project are due to methodological differences between the experiments reported here and previous studies. This project is the first to examine separately memory for actions and objects using whole action-object phrases in a WM context. It seems that splitting the action-object phrase during the retrieval stage hinders the enactment advantage, and especially so when enactment is recruited during the recall phase.

5.3.2 The enactment advantage – beyond motor systems

Previous research on enactment in WM has used instructions in which the central items to be remembered are the objects and their features while the motor actions themselves are limited to two verbs which are repeated within and throughout trials (Gathercole et al., 2008; Jaroslawska et al., 2016). For example, in Gathercole et al. (2008) the scoring of performance was grouped in terms of features (colour, object, container), items (colour-object and colour-container combination), sequences, and span. The latter two referred to the order of the instruction sequences and the number of sequences recalled correctly respectively. Thus, in that study memory for motor actions per se was not measured. The authors use the term *actions* in this context to refer not to single actions, but action-object pairs. In this study, the instructions were heavily focused on object and container features (2 actions vs. 15 objects), yet a strong enactment advantage was observed. As mentioned in chapter 2 (section 2.1.1) the same instructions were used by Jaroslawska et al. (2016) and Jaroslawska et al. (2018), who also observed strong enactment effects.

The sizeable enactment effects observed in these previous studies are in line with the argument discussed above, namely that the enactment advantage at recall heavily relies on the targeted objects on which the actions are to be performed. In other words, motor planning at encoding for future action benefits from the availability of objects in the environment that can support the formation of accurate motor plans (corresponding to the specific objects), and, given that motor planning matches later motor performance, a beneficial effect of action is observed.

Given that when splitting action-object information the enactment advantage disappears, it is suggested that the benefits of enactment in working memory do not solely rely on motor performance itself. If the enactment advantage relied purely on motoric aspects, then the experiments reported in this thesis should have shown strong enactment effects at both enactment encoding and enactment recall. Perhaps the complexity of instructions within the current paradigm, and the shifting between recall modes and probe types, may have imposed an additional load on WM, having a detrimental effect in performance. Nevertheless, if the enactment advantage goes beyond WM limitations as it has been argued (Yang et al., 2014), then enactment effects should still be observed in this project despite the imposed WM constraints. This suggests that the enactment effect relies on mechanisms beyond motor processing.

It is argued that the absence of strong enactment main effects in the experiments reported here reveal that the benefit of enactment relies on a rich and complex representation of “*action events*”. In this context, *action events* describe a rich representation which potentially includes motor actions, objects, motor action and object binding (Kormi-Nouri & Nilsson, 2001; Zhao et al., 2016), visuospatial locations and visual cues (Jaroslawska et al., 2016; Waterman et al., 2017), long term associations (Knopf, 1991), semantic and other contextual information (Engelkamp et al., 1990; Waterman et al., 2017). This assumption is based on numerous accounts in the literature that acknowledge the role of the aforementioned factors in aiding enactment performance (e.g. Engelkamp & Zimmer, 1995; Kormi-Nouri & Nilsson, 2001; Waterman et al., 2017).

In more detail, and as mentioned above (section 5.3.1), action-object bindings are thought to play an important role in enactment performance. As the study by Kormi-Nouri et al. (1994) showed, well integrated action-object pairs lead to greater enactment memory performance than poorly-integrated pairs. The results reported in this thesis also support this hypothesis given that it is the first study to split action and object memory at recall, and in doing so failed to replicate the strong enactment effects that are well established in the literature. Kormi-Nouri and Nilsson (2001) further stressed the importance of action-object bindings in enactment, suggesting that the action is defined by the object that is acted upon, in a manner that leads to a unified representation. For instance, according to this view, “lifting the pen” is perceived as one action. In other words, “lifting” and “pen” are encoded as one concept, not two separate items.

In turn, if physical performance, or the intent of it, serves as a “binding agent” which is integrating action and object information into one unit, then it might partly explain the enactment advantage. For example, consider the instructions used by Gathercole et al. (2008) “*pick up the blue ruler, then touch the red pencil*”. In this set of instructions, in a verbal condition, the participant would have to remember 6 items in the correct order (i.e. verb, colour, object x 2) or perhaps 4 items if the colour-object binding is automatic. However, in an enactment condition, assuming we accept Kormi-Nouri & Nilsson’s (2001) hypothesis, this would be remembering only 2 items (as action and object are bound together and registered as one item, i.e. *touching the red pencil*). In turn, this would decrease the memory load, leading to more accurate performance. In the case of enactment encoding, this binding would occur naturally by performing the action on a specific object. In the case of enactment recall, the motor plan would integrate action and object information for future performance.

This assumption is partially supported by Gathercole et al. (2008) and Yang, Gathercole and Allen (2016), who examined the instructions’ feature bindings and found that enactment led to superior binding of features compared to verbal recall. Further, it has been suggested that enactment performance is superior in cued recall (when either the object or action serve

as a retrieval cue) compared to free recall which also implies good binding of information in this condition (Earles & Kersten, 2000). Additionally, past research has also found that the enactment advantage was eliminated when objects were absent compared to being present. That is when participants perform the action-object phrase on an “imaginary object” performance is inferior to the condition where the participant performs the action on a real object (Steffens, Buchner & Wender, 2003). These findings, as well as the results obtained in this project, further support the assumption that action-object bindings play a crucial role in enactment performance.

However, at this point it should be noted that enactment effects have been observed in the absence of real objects when participants perform the actions symbolically (e.g. Engelkamp et al., 1991; Engelkamp & Zimmer, 1995; Jahn & Engelkamp, 2003) or when participants encode the information with their eyes closed (Yang et al., 2016). Thus, enactment with imagined objects still leads to an advantage compared to verbal encoding. This may suggest that successful binding does not require real objects to be physically present, as long as the object is present in *some* form (i.e. a representation). In other words, the physical action of mimicking *lifting a pen*, in the absence of a real pen, would still be concretised in the same way. That is, the motor action will still take a form (e.g. arm movement forward, distance between thumb and index finger, arm movement upward). This form, will still be much more specific in the action of *lifting an imaginary pen*, compared to the single action of *lifting* which is more abstract and where the corresponding action could take many forms. However, performing the action with a real object, compared to an imagined one, would lead to an even more accurate action representation. Indeed, when enactment with and without objects are compared directly, enactment with objects present is superior to enactment with objects absent (Steffens, Buchner, Wender & Decker, 2007). In addition, the majority of the studies that have examined enactment without real objects have used action-object pairs that have long term and semantic associations (e.g. smoke the cigarette, peel the apple, open the bottle) (Engelkamp et al., 1991; Jahn & Engelkamp, 2003). This further

indicates that the enactment advantage relies on semantic and long-term associations that help integrate action-object pairs.

Further, Yang et al. (2016), observed an enactment recall advantage when participants encoded the instructions with eyes closed (Experiment 3). In this case, it may be suggested that participants have already had visual access of the objects and their locations in space which may have facilitated the motor-imagery representations formed during encoding for future implementation. Indeed, participants' self-reports suggested that they used imagery strategies during encoding. Thus, it is suggested that action-object bindings play an important role in the enactment advantage, even if the objects are not physically present or visible. It can be argued that action-object *un-binding* (as in the current project) impairs enactment performance to a greater extent than the physical absence of objects does. This is because even in the absence of a physical object, the representation of the action-imaginary object binding is not interrupted throughout the study. In other words, encoding *lift the pen* in the absence of a pen will correspond to a- *lifting the pen*-action during recall. However, *lift the 3* at encoding and *lift the ball* at recall results in two different actions between encoding and recall. The second example impairs enactment performance to a greater extent because it interrupts or alters the action-object binding and, in consequence, the action itself.

Another factor that seems to play a role in enactment performance is visuospatial processing. For example, Jaroslawska et al. (2016), (for details see Chapter 3, section 3.1.2), found that when participants encoded the information by reading the instruction on the screen which prevented them from encoding cues in the environment compared to auditory encoding, the enactment recall advantage was eliminated. Similarly, in the current project, Experiments 5 and 6 that prevented visuospatial encoding by hiding the objects during presentation did not find enactment recall benefits. Further evidence for this assumption can be seen in the reliable correlations between enactment performance and the Corsi task in Waterman et al. (2017). In this study, successful enactment performance

reliably correlated with a VSPWM task. The authors in this paper also suggested that visuospatial cues play an important role in the enactment advantage.

A third factor that seems to play a role in enactment performance, which is also related to action-object bindings, is long-term semantic associations. Knopf (1991) examined verbal and enactment encoding for familiar and unfamiliar phrases. In this study participants heard instructions such as peel the kiwi fruit (familiar) or shave the kiwi fruit (unfamiliar). He found that although enactment performance was superior to verbal performance, the enactment advantage was reduced for unfamiliar compared to familiar action-object phrases. Performance after verbal encoding however, was similar for familiar and unfamiliar phrases. This suggests that the material used to study enactment also contributes to this effect by means of familiarity and semantic associations. It appears that familiar action-object phrases enhance enactment performance while they do not alter meaningfully to the same extent verbal memory performance.

Therefore, all these factors including motor learning, motor planning, action-object binding, visuospatial and contextual information, may individually or in combination, contribute to the enactment advantage. Thus, it is suggested that enactment benefits are not the result of simply motor processing but rather, of the multimodal richness *actions events*. In this context, *action events* describe the rich representations formed by enactment tasks (action-object bindings, motor processing, contextual information) and the rich environment (e.g. visuospatial locations and objects).

To sum up, previous research which found strong enactment effects in WM has predominantly examined memory for whole action-object phrases which themselves often contain strong contextual and semantic associations. This perhaps suggests that rather than motor memory being superior to verbal memory, the benefits of enactment partially stem from the richness of action events. For instance, the available cues in the participants' workspace (i.e. testing environment) may act as anchors, in that they provide a firm basis or a foundation that enables cognitive offloading (Risko & Gilbert, 2016). Cognitive offloading describes the process by which the agent is utilising resources in the environment to support

his or her cognitive processes. An example of cognitive offloading would be creating a shopping list so that one does not have to keep active in mind all the items one intends to buy. Another example is using a phone or a computer calendar to make notes and set reminders of one's day-to-day schedule. In the current example, objects present in the participant's environment may trigger the formation of motor plans and create action-object bindings to facilitate performance. In this scenario, an object may provide the cue for the appropriate action. Furthermore, it has been suggested that external objects (such as a notepad, one's phone) not only enable efficiency by offloading, but can actively support one's cognitive performance (Zhang, 1997). For example, upon seeing a book left on a desk someone may be reminded that they must return it to the library. In such an example, the object (book) serves as a cue that may actively facilitate one's memory. Relating this to the current topic of discussion, objects may serve as cues for retrieval of the performed action, a visuospatial location may act as a cue for the object, or a series of visuospatial locations may serve as cues for order information. Furthermore, assuming that action-object bindings lead to a unified representation (as described above), this additionally reduces memory load in conditions that involve enactment.

5.3.3 Underlying Mechanisms of Enactment

The current findings suggest that although the enactment effect has strong roots in motor processing, the enactment advantage is a result of rich and complex representations that include motor processes, action-object binding information, semantic long-term associations. Combinations of these factors constitute *action events* that enhance enactment memory performance. A crucial question that arises with this assumption is the role of Working Memory in this process. The current discussion is unable to definitively answer this question but based on the correlational findings from this project and previous studies (see section 5.2.2), it is suggested that both verbal and visuospatial storage contribute to some extent in enactment performance. However, the hypothesis of *action events*, also implies reduced

WM load under enactment compared to verbal conditions. This is achieved by two processes both related to action-object bindings. First, assuming the successful binding of action-object phrases, objects in the environment serve as cues for recall, enabling cognitive offloading thus reducing WM demands. Second, the action-object bindings under enactment, result in the chunking of information thus, again, reducing cognitive load as an action-object phrase is perceived as one item. A candidate framework that can account for these processes within WM is the Episodic Buffer (EB). According to this account (Baddeley, Allen & Hitch (2010), the EB is a system that integrates representations from different modalities, in other words it is responsible for binding multimodal information. Thus, it may be suggested that the EB plays a crucial role in action events by means of integrating various representations into a unified framework that in turn, facilitate performance. The binding process itself is not thought to involve additional attentional resources (Allen, Hitch & Baddeley, 2009). Thus, if the integration of action events relies predominantly on the EB, instead of other WM subsystems, this may partly explain the enactment advantage observed when other WM subsystems are preoccupied by distractor tasks. Future research should examine enactment in relation to the EB in order to explore this notion further. For example, a future study could examine whether disrupting the EB affects negatively enactment compared to verbal performance.

It is also suggested that physical performance at encoding and at recall may involve partly different processes namely *motor learning* and *motor planning* respectively. As discussed above, it is hypothesised, that motor performance at presentation results in the formation of an implicit motor sequence schema during physical performance, which in turn facilitates memory at recall. At this stage of encoding, action-object bindings play an important role during actual performance as the action becomes concrete by being performed on something or in relation to something. Experiments 2, 3 and 4 in this project support this assumption as enactment encoding facilitated action memory. In agreement with previous research, this thesis also suggests that enactment recall benefits rely on motor planning for future physical implementation. Further it is suggested that action-object

bindings play a crucial role in the successful formation of those plans as they facilitate the concretisation of actions. This is based on the observation that splitting the action-object information when enactment is manipulated at recall hinders the enactment advantage (Experiments 2, 5 and 6).

5.3.4 The one-component hypothesis- revisited

The results obtained in this project are not necessarily incompatible with the motor store hypothesis that suggests that enactment encoding and enactment recall rely on the same system. Although it is suggested here that enactment encoding and recall rely on different processes, these processes could be operated by the same system. The one-component hypothesis suggests that the motor store maintains action information whether planned or already performed (Jaroslawska et al., 2016), however the exact processes involved in enactment encoding and recall are underspecified. Jaroslawska et al. (2016) suggested that after enactment encoding, the performed action sequence would be represented in the motor store, while enactment recall benefits rely on motor planning which also takes place in the motor store. This is not inconsistent with the view proposed in this thesis as enactment encoding is also thought to lead to an action representation (i.e. motor learning).

Furthermore, here it has been argued that the enactment advantage is the result of a synthesis of factors, rather than purely motoric processing. The latter also does not necessarily contradict the motor store hypothesis. For instance, it has been suggested that the motor store processes motor, spatial and temporal information and that it works in conjunction with WM, (although the exact nature of these processes or its relation to WM, are unclear) (Jaroslawska et al., 2018).

The main contradiction between the motor store hypothesis and the position proposed here is the former's assumption that if enactment encoding and enactment recall relied on different processes, then enactment at both stages would lead to double enactment benefits. Indeed, the findings from previous research (e.g. Allen & Waterman, 2015; Jaroslawska et al., 2016; Waterman et al., 2017) as well as this project (Experiments 1 and 2), show that

enactment at both encoding and recall does not lead to superior performance compared to enactment at one stage only. In fact, Experiment 2 in this project showed that enactment at one stage (either encoding or recall) led to superior performance than enactment at both stages for memory for objects. Therefore, experimental evidence suggests that enactment at both encoding and recall does not lead to double enactment benefits. However, this does not necessarily mean that enactment at encoding and recall involve the same processes, but rather, it may suggest that enactment benefits of encoding and of recall manifest at the same timeframe.

In other words, according to the literature, enactment recall benefits rely on the formation of motor plans during encoding. Thus, it follows that enactment encoding and enactment recall motor processes, that presumably facilitate performance, both take place during the encoding phase. Therefore, enactment at both stages cannot possibly lead to double benefits because both enactment encoding and enactment recall benefits rely on processes that take place during that same encoding phase. If enactment takes place at encoding, then the participant is preoccupied physically performing the actions. It may be suggested that during that phase implicit learning takes place, so that the representations of the executed motor movements carry the sequential imprint for future recall (see section 5.2.5). If enactment is manipulated at recall, during the encoding phase the participant is preparing for future action generation thus motor planning takes place during presentation. In the case of enactment at both stages, enactment at encoding processes (i.e. actual physical performance) would compete or interfere with motor planning for future performance. In other words, during encoding, participants either actually perform or they plan to perform.

Further evidence that enactment encoding processes may obscure enactment recall benefits (formation of motor plans) were provided by Engelkamp (1997). In a series of four experiments, the author examined benefits of enactment encoding vs motor planning (by crossing enactment and verbal encoding and recall). More specifically, participants had to memorise a long list of action object phrases (varying across experiments from 30-60 phrases), with recall being either congruent with participants' expectation or incongruent (as

in Koriat et al., 1990). Thus in some trials participants were told to expect enactment recall but actually received a free recall pen and paper test instead.

In the first two experiments enactment or verbal encoding was manipulated within subjects (and blocks), and recall (enactment or verbal) between subjects. In Experiment 3 both encoding and recall were manipulated between-subjects. The findings suggested that when enactment encoding and recall were manipulated within-subjects the motor planning advantage disappeared. That is, motor planning performance was similar to verbal recall. Additionally, enactment encoding with verbal recall was reliably more accurate compared to enactment encoding with enactment recall. Experiment 3 using a between-subjects design did not replicate the latter finding, namely that double enactment was worse than enactment encoding with verbal recall. It did show however that motor planning led to more accurate performance in the verbal encoding group. This was found when actual enactment took place at recall (Experiment 1) and when participants anticipated enactment recall but received a surprise verbal test instead (Experiments 2 and 3). Finally, in Experiment 4 participants encoded instructions verbally and they either anticipated verbal recall or motor recall. The actual test was a free recall pen and paper test. In this last experiment, anticipation of enactment recall led to reliably better performance compared to the verbal recall anticipation. These findings may provide further evidence that physical performance at encoding interferes with motor planning for future recall as when enactment recall followed enactment encoding, benefits of enactment recall were hindered. When encoding was purely verbal however, enactment recall lead to superior performance compared to verbal recall (both actual and anticipated, Experiments 3 and 4). Indeed, the author suggested that enactment encoding and recall rely on slightly different mechanisms. He proposed that enactment recall relies on motor planning during encoding, but enactment encoding involves additional motoric processing which includes- but exceeds -simple motor planning (Engelkamp, 2001).

In a further study, Jahn and Engelkamp (2003) examined enactment encoding vs enactment recall (i.e. motor planning) benefits using pure lists and mixed lists. In pure lists

participants encoded instructions in only one condition either verbal, enactment or motor planning. In the latter condition, during encoding participants were told to encode instructions for future performance. In mixed lists, encoding mode varied within blocks so that in some trials participants enacted the instructions and in others they were instructed to plan for future enactment recall. They found that when enactment encoding and enactment recall were manipulated in mixed lists (within blocks), performance after enactment encoding was greater than in the motor planning condition. That is, enactment recall benefits were hindered. However, when encoding was manipulated in pure lists (different blocks), enactment encoding (with verbal recall) and enactment recall (after auditory encoding) lead to similar levels of performance. These findings further show that when enactment encoding and enactment recall are manipulated separately (in different blocks or between subjects) both lead to superior performance compared to verbal conditions. However, when enactment encoding and enactment recall are manipulated within-subjects (or within blocks), enactment at recall benefits are hindered. This supports the assumption that enactment encoding and enactment recall may involve different processes but that enactment encoding obscures motor planning when the two occur simultaneously.

Finally, the findings reported in Chapter 2 may partially support the suggestion that when enactment encoding and enactment recall are manipulated simultaneously, enactment recall benefits decrease. In the experiments reported in that chapter, children showed a benefit of enactment recall for the actions while adults did not (see Chapter 2, sections 2.2.2 and 2.3.2 respectively). A main difference between the two experiments was that children completed the study in two sessions while adults completed the study in one session. In more detail, children completed the two conditions involving enactment encoding in one session and the two conditions involving verbal encoding in the other session, approximately one week apart. Therefore, the separation of the conditions involving enactment and verbal encoding may have contributed to the increase of enactment recall benefits observed in children. On the contrary, for adults, benefits of enactment recall may have been overshadowed by enactment encoding processes as both enactment encoding and enactment recall conditions

took place within the same session. This explanation is in line with the findings from Jahn and Engelkamp (2003) described above who observed similar effects.

Additional support for the assumption that enactment encoding processes may interfere with motor planning can be seen in the study by Allen and Waterman (2015), in which enactment encoding led to superior performance in verbal but not enactment recall. Further, Jaroslawska et al. (2016) and Waterman et al. (2017) also found that enactment recall benefits were reduced after enactment encoding. The authors in these studies took this as evidence that enactment encoding and recall rely on the same type of processing but the current explanation could also account for these findings.

Together, the findings presented in this section provide support for the assumption that enactment encoding processes interfere with motor planning for future performance. Further research into the motor store may offer a better understanding of the system and how it might support these different processes involved at motor encoding and motor recall.

More broadly, the findings from this project are in line with more extended accounts of cognition, such as embodied, situated and distributed cognition (for a review see Wilson, 2002). For instance, the current experiments showed that sensorimotor processes can affect directly WM performance. This is because, as in previous studies in the literature, the current project found that physical performance facilitates memory for spoken instructions (Experiments 1, 2, 3 and 4). Additionally, this project provided evidence that manipulating the environment may have an effect in memory performance. For example, it may be the case that enactment recall did not facilitate performance in Experiments 5 and 6 partly because the objects were hidden during encoding thus hindering any visuospatial encoding or object-location bindings. These findings suggest that cognitive performance is dependent on a variety of external factors in a very dynamic fashion as discussed in the previous section.

5.4 Opportunities for future research

First, in order to clarify whether the effects observed in this project were the product of the experiment manipulations rather than flaws in methodology, the studies reported here should be replicated with some procedural changes. These suggestions are discussed first. The rest of the section discusses how future research could examine some of the theoretical implications offered in this thesis.

Future research should attempt to replicate the order reconstruction benefit for actions under enactment that was observed in Experiments 3 and 4 in this thesis using a different set of objects. There is the possibility that order reconstruction for objects was superior in verbal recall due to the nature of the objects (i.e. these being numbers).

In connection to the above, there is the possibility that the absence of reliable main enactment effects in Experiments 3, 4, 5, and 6 was due to the additional item-order manipulation at recall. In these experiments participants at the end of the trial had to either reconstruct the order of the stimuli or to recognise the correct items presented. Perhaps this additional manipulation (item vs order) overcomplicated the experimental procedure thus obscuring any possible effects. However, this design was selected in order to examine whether actions or objects carry *inherently* better order or item information in enactment vs verbal encoding and recall. Therefore, it was crucial that participants were not purposefully attempting to memorise only order or only item information. Hence item recognition and order reconstruction were manipulated within blocks and not separately. Nevertheless, a future study could examine action vs object memory in enactment and verbal encoding and recall where order reconstruction and item recognition are manipulated in different blocks. This may produce more reliable and stable effects as fewer variables will be manipulated simultaneously.

Crucially, in order to examine whether the splitting of action-object pairs in these studies are indeed responsible for the reduced enactment effects, a future study should examine enactment for whole action-object phrases using the IAFT material. This would establish

whether the absence of enactment recall effects was the result of the splitting of action-object information at recall.

The action-object phrases used in this project were chosen precisely because they do not carry semantic associations and do not form meaningful phrases. This was essential in order to examine the purely motor involvement (as much as this was possible). There is the possibility however, that the partial absence of strong of enactment effects in this series of experiments is not due to the splitting of action-object phrases at recall, but due to poor integration of action-object phrases at encoding. This is because the action-object pairs used (e.g. shake the 1) did not afford good integration (i.e. binding). As noted, previous research (Kormi-Nouri et al., 1994) has shown that enactment recall (but not enactment encoding) benefits are hindered when poorly integrated action-object pairs are used compared to well-integrated pairs. However, note that if the action-object phrases used here have reduced enactment benefits that would further suggest that the enactment advantage is the product of rich processing of action events. In other words, it would suggest that superior performance in enactment conditions relies on aspects beyond purely motoric information (such as semantic long-term associations). Crucially, it would provide further support regarding the importance of action-object bindings in enactment. In order to examine this hypothesis a project should investigate enactment and verbal encoding and recall manipulating probe type (action or object memory) but with well-integrated action-object phrases. If the benefits of enactment were hindered in this project because action-object pairs were poorly integrated, and not because they were split at recall, an enactment benefit should be observed for well-integrated pairs.

Another related issue to be addressed is whether the enactment advantage is the result of better memory for “action events” or whether enactment superiority over verbal learning can be attributed to purely motoric processing. In order to answer this question, future studies should compare memory for action-object phrases to memory for single action verbs in WM under verbal and enactment encoding and recall, in children and adults. If the enactment advantage (i.e. difference between enactment and verbal performance) for whole

action-object phrases is greater than the enactment advantage for single actions, this would suggest that enactment does not rely on purely motor processing. If the enactment advantage for action-object phrases and single verbs is equivalent this would suggest that enactment relies mainly on purely motor processing and that other contextual information does not add much to the enactment effect.

In turn, comparing enactment encoding to enactment recall for well-integrated pairs for “action vs object recall” to “action plus object recall” would provide some evidence regarding whether the un-binding of information at recall impairs performance. That is, if enactment for whole action-object phrases leads to better performance compared to memory for only actions or only objects, that would suggest that the un-binding of the action-object pair at recall impairs performance. Additionally, this experiment would also provide further information regarding the different processes involved at enactment encoding and recall. For instance, it would be informative to examine if the splitting of action-object phrases when enactment is manipulated at recall hinders performance to a greater extent than when enactment is manipulated at encoding. If the results supported this assumption, this would suggest that indeed action-object bindings are more important for successful motor planning than successful memory performance after motor learning.

Furthermore, examining enactment at both encoding and recall under this paradigm would provide further evidence regarding different processes at enactment encoding and recall. In other words, if double enactment prevents the formation of motor plans (as during encoding only one motor process can occur and this is motor implementation), then it would be expected that enactment recall would not be as impaired after the un-binding of action-object phrases. This is because enactment recall performance would not be based on motor planning that would otherwise be impaired, but on motor learning. As suggested here, un-binding at enactment recall is more detrimental to performance than un-binding after enactment encoding. Therefore, if double enactment relies on motor learning only, the effects of splitting action-object phrases at enactment recall should not be as detrimental to memory performance as when enactment is manipulated at recall only.

Another way to investigate further whether enactment encoding and enactment recall involve different processes would be to compare the two phases with regards to order information. The present study showed evidence that enactment encoding (i.e. physical performance) facilitates sequential information for the performed actions. Enactment recall however, did not show the same pattern. Thus, a follow-up study should examine memory for order reconstruction after enactment encoding and enactment recall. If the current findings are replicated, namely that compared to verbal encoding, enactment at presentation leads to better memory for order but enactment at recall does not, this would suggest that enactment encoding and recall involve – at least to some extent- different processes.

Another question raised in this thesis that requires further investigation is whether enactment at WM and LTM involves the same mechanisms. A study that examines memory for actions vs objects in immediate and delayed recall in order reconstruction and item recognition would provide further insights regarding the nature of the enactment effect.

Finally, although a few studies have established that enactment recall does not rely on WM resources in adults, research with children has not examined this assumption fully. In order to gain a better understanding of the nature of the motor store, future research should employ a similar paradigm to Yang et al. (2014) and Jaroslawska et al. (2018) with children. In this paradigm participants engage in a series of distractor tasks during verbal encoding that aim to tap different WM subcomponents (i.e. phonological loop, central executive, visuospatial sketchpad) and the motor store (e.g. see Jaroslawska et al., 2018). Subsequent recall is either verbal or through enactment. This experiment would establish if the enactment advantage observed in adults in this type of experiment is also present in children. If this is the case, it would suggest that the motor process involved in enactment encoding and recall remain stable across development while developmental differences in overall performance are due to WM changes as argued in this thesis.

5.5 Conclusion

The current project aimed to examine the underlying mechanisms of the enactment effect by investigating separately action and object memory after enactment encoding and recall. The overall findings suggest that, as argued in the literature, the enactment effect is indeed rooted in motor processing. However, the availability of motor information is not sufficient for superior performance. It is suggested that the enactment advantage is the product of rich *action events* that include action-object bindings, visuospatial information, and semantic long-term associations. Based on the current findings, it is further proposed that the enactment advantage at encoding and at recall rely on different motor processes, namely motor learning and motor planning respectively. This assumption is based on the observation that enactment encoding facilitated memory performance and order information (Experiments 2, 3 and 4) while enactment recall did not. Additionally, enactment recall performance correlated meaningfully with WM measures, but enactment encoding did not, at least not in this project. These differences, along with evidence from the literature mentioned above, may imply that enactment encoding, and enactment recall involve slightly different processes. Further, it is hypothesised that action-object bindings play a fundamental role in the successful formation of motor plans for future action execution, as it is thought that the un-binding of such information at retrieval eliminates the enactment recall advantage. Future studies should investigate further the conclusions made in this thesis and test the aforementioned theoretical assumptions in a direct and systematic manner.

6 References

- Allen, R. J., Hitch, G. J., & Baddeley, A. D. (2009). Cross-modal binding and working memory. *Visual Cognition*, 17(1-2), 83-102.
- Allen, R. J., & Waterman, A. H. (2015). How does enactment affect the ability to follow instructions in working memory? *Memory and Cognition*, 43(3), 555–561.
<https://doi.org/10.3758/s13421-014-0481-3>
- Ashe, J., Lungu, O. V., Basford, A. T., & Lu, X. (2006). Cortical control of motor sequences. *Current Opinion in Neurobiology*, 16(2), 213–221.
<https://doi.org/10.1016/j.conb.2006.03.008>
- Atkinson, R., Shiffrin, R. (1968). Human Memory: A Proposed System and Its Control Processes. *Scientists Making a Difference*, 115–118.
<https://doi.org/10.1017/CBO9781316422250.025>
- Attout, L., Van der Kaa, M. A., George, M., & Majerus, S. (2012). Dissociating short-term memory and language impairment: The importance of item and serial order information. *Aphasiology*, 26(3-4), 355-382.
- Baddeley, A. D. (1986). *Working Memory*. Oxford, UK: Oxford University Press
- Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology Section A*, 49(1), 5-28.
- Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in cognitive sciences*, 4(11), 417-423.
- Baddeley, A.D. (2007). *Working Memory, Thought and Action*. Oxford: Oxford University Press.
- Baddeley, A. (2010). Working memory. *Current biology*, 20(4), R136-R140.
- Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of learning and motivation* (Vol. 8, pp. 47-89). Academic press.
- Baddeley, A., Allen, R. J., & Hitch, G. (2010). Investigating the episodic buffer. *Psychologica Belgica*, 50(3), 223-243.

- Barsalou, L. W., Simmons, W. K., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in cognitive sciences*, 7(2), 84-91.
- Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The Complexities of Complex Span: Explaining Individual Differences in Working Memory in Children and Adults. *Journal of Experimental Psychology: General*, 132(1), 71–92.
<https://doi.org/10.1037/0096-3445.132.1.71>
- Bjork, E. L., & Healy, A. F. (1974). Short-term order and item retention. *Journal of Verbal Learning and Verbal Behavior*, 13(1), 80-97.
- Brooks, B. M., & Gardiner, J. M. (1994). Age differences in memory for prospective compared with retrospective subject-performed tasks. *Memory & Cognition*, 22(1), 27–33. <https://doi.org/10.3758/BF03202758>
- Camos, V., Lagner, P., & Loaiza, V. M. (2017). Maintenance of item and order information in verbal working memory. *Memory*, 25(8), 953-968.
- Charlesworth, L. A., Allen, R. J., Morson, S., Burn, W. K., & Souchay, C. (2014). Working Memory and the Enactment Effect in Early Alzheimer's Disease. *ISRN Neurology*, 2014, 1–5. <https://doi.org/10.1155/2014/694761>
- Cohen, R. L. (1981). On the generality of some memory laws. *Scandinavian Journal of Psychology*, 22(1), 267-281.
- Cohen, R. L. (1989). Memory for action events: The power of enactment. *Educational Psychology Review*, 1(1), 57–80. <https://doi.org/10.1007/BF01326550>
- Cohen, R. L., & Stewart, M. (1982). How to avoid developmental effects in free recall. *Scandinavian Journal of Psychology*, 23(1), 9-15.
- Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, 7(12), 547–552.
<https://doi.org/10.1016/j.tics.2003.10.005>
- Conway, A. R. a, Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks : A methodological review and user ' s guide,

12(5), 769–786.

- Cowan, N., Naveh-Benjamin, M., Kilb, A., & Saults, J. S. (2006). Life-span development of visual working memory: When is feature binding difficult?. *Developmental psychology*, 42(6), 1089.
- Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior*, 11(6), 671-684.
- Craik, F. I., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of experimental Psychology: general*, 104(3), 268.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, 19(4), 450-466.
- DeLosh, E., Psychology, M. M.-J. of E., & 1996, undefined. (n.d.). The role of order information in free recall: Application to the word-frequency effect. *Psycnet.Apa.Org*. Retrieved from <http://psycnet.apa.org/fulltext/1996-05780-005.html>
- Earles, J. L., & Kersten, A. W. (2000). Adult age differences in memory for verbs and nouns. *Aging, Neuropsychology, and Cognition*, 7(2), 130-139.
- Engelkamp, J. (1997). Memory for to-be-performed tasks versus memory for performed tasks. *Memory and Cognition*, 25(1), 117–124. <https://doi.org/10.3758/BF03197289>
- Engelkamp, J. (2001). Action memory: A systems-oriented approach. In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkamp, R. KormiNouri, & M. A. Foley (Eds.). *Memory for action: A distinct form of episodic memory?* (pp. 49-96). New York: Oxford University Press.
- Engelkamp, J., & Cohen, R. L. (1991). Current issues in memory of action events. *Psychological Research*, 53(3), 175–182. <https://doi.org/10.1007/BF00941384>
- Engelkamp, J., & Dehn, D. M. (2000). Item and Order Information in Subject-Performed Tasks and Experimenter-Performed Tasks. *Journal of Experimental Psychology: Learning Memory and Cognition*, 26(3), 671–682. <https://doi.org/10.1037/0278-7393.26.3.671>
- Engelkamp, J., & Jahn, P. (2003). Lexical, conceptual and motor information in memory for

- action phrases: A multi-system account. *Acta Psychologica*, 113(2), 147–165.
[https://doi.org/10.1016/S0001-6918\(03\)00030-1](https://doi.org/10.1016/S0001-6918(03)00030-1)
- Engelkamp, J., Jahn, P., & Seiler, K. H. (2003). The item-order hypothesis reconsidered: The role of order information in free recall. *Psychological Research*, 67(4), 280–290.
<https://doi.org/10.1007/s00426-002-0118-1>
- Engelkamp, J., & Krumnacker, H. (1980). Image-and motor-processes in the retention of verbal materials. *Zeitschrift für experimentelle und angewandte Psychologie*.
- Engelkamp, J., Mohr, G., & Zimmer, H. D. (1991). Pair-relational encoding of performed nouns and verbs. *Psychological Research*, 53(3), 232–239.
<https://doi.org/10.1007/BF00941392>
- Engelkamp, J., Seiler, K. H., & Zimmer, H. D. (2004). Memory for actions: Item and relational information in categorized lists. *Psychological Research*, 69(1-2), 1-10.
- Engelkamp, J., & Zimmer, H. D. (1984). Motor programme information as a separable memory unit. *Psychological Research*, 46(3), 283-299.
- Engelkamp, J., & Zimmer, H. D. (1989). Memory for action events: A new field of research. *Psychological Research*, 51, 153-157.
- Engelkamp, J., & Zimmer, H. D. (1995). Similarity of movement in recognition of self-performed tasks and of verbal tasks. *British Journal of Psychology*.
<https://doi.org/10.1111/j.2044-8295.1995.tb02559>
- Engelkamp, J., Zimmer, H. D., & Mohr, G. (1990). Differential memory effects of concrete nouns and action verbs. *Zeitschrift für Psychologie mit Zeitschrift für angewandte Psychologie*.
- Engelkamp, J., Zimmer, H. D., Mohr, G., & Sellen, O. (1994). Memory of self-performed tasks: Self-performing during recognition. *Memory & Cognition*, 22(1), 34-39.
- Foley, M. A., & Johnson, M. K. (1985). Confusions between memories for performed and imagined actions: A developmental comparison. *Child development*, 1145-1155.
- Gathercole, S. E., Durling, E., Evans, M., Jeffcock, S., & Stone, S. (2008). Working memory abilities and children's performance in laboratory analogues of classroom

- activities. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, 22(8), 1019-1037.
- Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The Structure of Working Memory from 4 to 15 Years of Age. *Developmental Psychology*, 40(2), 177–190. <https://doi.org/10.1037/0012-1649.40.2.177>
- Glenberg, A., Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin and Review*, 9(3), 558–565. [https://doi.org/https://doi.org/10.3758/BF03196313](https://doi.org/10.3758/BF03196313)
- Golly-Häring, C., & Engelkamp, J. (2003). Categorical-relational and order-relational information in memory for subject-performed and experimenter-performed actions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(5), 965.
- Healy, A. F. (1974). Separating item from order information in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 13(6), 644-655.
- Hunt, R. R., & Einstein, G. O. (1981). Relational and item-specific information in memory. *Journal of Verbal Learning and Verbal Behavior*, 20(5), 497-514.
- Jahn, P., & Engelkamp, J. (2003). Design-Effects in Prospective and Retrospective Memory for Actions. *Experimental Psychology*, 50(1), 4–15. <https://doi.org/10.1027//1618-3169.50.1.4>
- James, K. H., & Swain, S. N. (2011). Only self-generated actions create sensori-motor systems in the developing brain. *Developmental science*, 14(4), 673-678.
- Jaroslawska, A. J., Gathercole, S. E., Allen, R. J., & Holmes, J. (2016). Following instructions from working memory: Why does action at encoding and recall help? *Memory and Cognition*, 44(8), 1183–1191. <https://doi.org/10.3758/s13421-016-0636-5>
- Jaroslawska, A. J., Gathercole, S. E., & Holmes, J. (2018). Following instructions in a dual-task paradigm: Evidence for a temporary motor store in working memory. *Quarterly Journal of Experimental Psychology*, 71(11), 2439–2449. <https://doi.org/10.1177/1747021817743492>
- Jarrold, C., & Towse, J. N. (2006). Individual differences in working

- memory. *Neuroscience*, 139(1), 39-50.
- Jeannerod, M. (2001). Neural simulation of action: a unifying mechanism for motor cognition. *Neuroimage*, 14(1), S103-S109.
- Kane, M. J., Tuholski, S. W., Hambrick, D. Z., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, 133(2), 189–217. <https://doi.org/10.1037/0096-3445.133.2.189>
- Knopf, M. (1991). Having shaved a kiwi fruit: Memory of unfamiliar subject-performed actions. *Psychological Research*, 53(3), 203-211.
- Koriat, A., Ben-Zur, H., & Nussbaum, A. (1990). Encoding information for future action: Memory for to-be-performed tasks versus memory for to-be-recalled tasks. *Memory & Cognition*, 18(6), 568–578. <https://doi.org/10.3758/BF03197099>
- Koriat, A., & Pearlman-Avnion, S. (2003). Memory organization of action events and its relationship to memory performance. *Journal of Experimental Psychology: General*, 132(3), 435.
- Kormi-Nouri, R. & Nilsson, L.-G. (2001). The motor component is not crucial! In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkamp, R. Kormi-Nouri & M. A. Foley (Eds.), *Memory for action: A distinct from episodic memory?* (pp. 97–111). Oxford: Oxford University press.
- Kormi-Nouri, R., Nyberg, L., & Nilsson, L. G. (1994). The effect of retrieval enactment on recall of subject-performed tasks and verbal tasks. *Memory & Cognition*, 22(6), 723–728. <https://doi.org/10.3758/BF03209257>
- Masson, M. E. (2011). A tutorial on a practical Bayesian alternative to null-hypothesis significance testing. *Behavior research methods*, 43(3), 679-690.
- McDaniel, M., Einstein, G., ... E. D.-J. of, & 1995, U. (n.d.). The bizarreness effect: It's not surprising, it's complex. *Psycnet.Apa.Org*. Retrieved from <http://psycnet.apa.org/fulltext/1995-28017-001.html>
- Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our

- capacity for processing information. *Psychological review*, 63(2), 81.
- Mulligan, N. W. (1999). The effects of perceptual interference at encoding on organization and order: Investigating the roles of item-specific and relational information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25(1), 54.
- Nairne, J. S., Riegler, G. L., & Serra, M. (1991). Dissociative Effects of Generation on Item and Order Retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 17(4), 702–709. <https://doi.org/10.1037/0278-7393.17.4.702>
- Nilsson, L. G., Nyberg, L., Klingberg, T., Åberg, C., Persson, J., & Roland, P. E. (2000). Activity in motor areas while remembering action events. *Neuroreport*, 11(10), 2199-2201.
- Nitsche, M. A., Schauenburg, A., Lang, N., Liebetanz, D., Exner, C., Paulus, W., & Tergau, F. (2003). Facilitation of implicit motor learning by weak transcranial direct current stimulation of the primary motor cortex in the human. *Journal of cognitive neuroscience*, 15(4), 619-626.
- Nyberg, L., Petersson, K. M., Nilsson, L. G., Sandblom, J., Åberg, C., & Ingvar, M. (2001). Reactivation of motor brain areas during explicit memory for actions. *Neuroimage*, 14, 521-528.
- Norman, D. A., & Shallice, T. (1986). Attention to action. In *Consciousness and self-regulation* (pp. 1-18). Springer, Boston, MA.
- Olofsson, U. (1996). The effect of enactment on memory for order. *Psychological research*, 59(1), 75-79.
- Paivio, A. (1986). *Mental Representations: A Dual-Coding Approach*, Oxford University Press, New York.
- Peirce, J. W. (2009). Generating stimuli for neuroscience using PsychoPy. *Frontiers in neuroinformatics*, 2, 10.
- Pereira, A., De Mendonça, A., Silva, D., Guerreiro, M., Freeman, J., & Ellis, J. (2015). Enhancing prospective memory in mild cognitive impairment: The role of enactment. *Journal of Clinical and Experimental Neuropsychology*, 37(8), 863–877.

<https://doi.org/10.1080/13803395.2015.1072499>

- Pulvermüller, F., Moseley, R. L., Egorova, N., Shebani, Z., & Boulenger, V. (2014). Motor cognition-motor semantics: Action perception theory of cognition and communication. *Neuropsychologia*, 55(1), 71–84.
- Risko, E. F., & Gilbert, S. J. (2016). Cognitive offloading. *Trends in Cognitive Sciences*, 20(9), 676-688. <https://doi.org/10.1016/j.neuropsychologia.2013.12.002>
- Saltz, E., & Dixon, D. (1982). Let's pretend: The role of motoric imagery in memory for sentences and words. *Journal of Experimental Child Psychology*, 34(1), 77–92. [https://doi.org/10.1016/0022-0965\(82\)90032-7](https://doi.org/10.1016/0022-0965(82)90032-7)
- Saltz, E., & Donnenwerth-Nolan, S. (1981). Does motoric imagery facilitate memory for sentences? A selective interference test. *Journal of Verbal Learning and Verbal Behavior*, 20(3), 322-332.
- Schult, J., Von Stülpnagel, R., & Steffens, M. C. (2014). Enactment versus observation: Item-specific and relational processing in goal-directed action sequences (and lists of single actions). *PLoS ONE*, 9(6). <https://doi.org/10.1371/journal.pone.0099985>
- Shebani, Z., & Pulvermüller, F. (2013). Moving the hands and feet specifically impairs working memory for arm-and leg-related action words. *Cortex*, 49(1), 222-231.
- Smyth, M. M., & Pendleton, L. R. (1989). Working memory for movements. *The quarterly Journal of experimental Psychology*, 41(2), 235-250.
- Smyth, M. M., & Pendleton, L. R. (1990). Space and movement in working memory. *The Quarterly Journal of Experimental Psychology*, 42(2), 291-304.
- Steffens, M. C., Buchner, A., & Wender, K. F. (2003). Quite ordinary retrieval cues may determine free recall of actions. *Journal of Memory and Language*, 48(2), 399-415.
- Steffens, M. C., Buchner, A., Wender, K. F., & Decker, C. (2007). Limits on the role of retrieval cues in memory for actions: Enactment effects in the absence of object cues in the environment. *Memory & cognition*, 35(8), 1841-1853.
- Tanji, J. (2001). Sequential Organization of Multiple Movements: Involvement of Cortical Motor Areas. *Annual Review of Neuroscience*, 24(1), 631–651.

<https://doi.org/10.1146/annurev.neuro.24.1.631>

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, 8(6), 769–800.

<https://doi.org/10.1080/13506280042000144>

Vigliocco, G., Vinson, D. P., Druks, J., Barber, H., & Cappa, S. F. (2011). Nouns and verbs in the brain: A review of behavioural, electrophysiological, neuropsychological and imaging studies. *Neuroscience and Biobehavioral Reviews*, 35(3), 407–426.

<https://doi.org/10.1016/j.neubiorev.2010.04.007>

Waterman, A. H., Atkinson, A. L., Aslam, S. S., Holmes, J., Jaroslawska, A., & Allen, R. J. (2017). Do actions speak louder than words? Examining children's ability to follow instructions. *Memory and Cognition*, 45(6), 877–890. <https://doi.org/10.3758/s13421-017-0702-7>

Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of experimental psychology: learning, memory, and cognition*, 15(6), 1047.

Willingham, D. B., Wells, L. A., Farrell, J. M., & Stemwedel, M. E. (2000). Implicit motor sequence learning is represented in response locations. *Memory & Cognition*, 28(3), 366-375.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin and Review*, 9(4), 625–636. <https://doi.org/10.3758/BF03196322>

Wojcik, D. Z., Allen, R. J., Brown, C., & Souchay, C. (2011). Memory for actions in autism spectrum disorder. *Memory*, 19(6), 549-558.

Yang, T., Gathercole, S. E., & Allen, R. J. (2014). Benefit of enactment over oral repetition of verbal instruction does not require additional working memory during encoding.

Psychonomic Bulletin and Review, 21(1), 186–192. <https://doi.org/10.3758/s13423-013-0471-7>

Yang, T. X., Allen, R. J., & Gathercole, S. E. (2016). Examining the role of working memory

- resources in following spoken instructions. *Journal of Cognitive Psychology*, 28(2), 186–198. <https://doi.org/10.1080/20445911.2015.1101118>
- Yang, T. X., Jia, L. X., Zheng, Q., Allen, R. J., & Ye, Z. (2018). Forward and backward recall of serial actions: Exploring the temporal dynamics of working memory for instruction. *Memory & cognition*, 1-13.
- Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive science*, 21(2), 179-217.
- Zhao, M. F., Zimmer, H. D., Zhou, X., & Fu, X. (2016). Enactment supports unitisation of action components and enhances the contribution of familiarity to associative recognition. *Journal of Cognitive Psychology*, 28(8), 932-947.
- Zimmer, H. D., & Engelkamp, J. (1985). An attempt to distinguish between kinematic and motor memory components. *Acta Psychologica*, 58(1), 81-106.
- Zimmer, H. D., Cohen, R. L., Foley, M. A., Gynn, M. J., Engelkamp, J., & Kormi-Nouri, R. (2001). *Memory for action: A distinct form of episodic memory?*. New York: Oxford University Press.
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